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AMERICAN SOCIETY OF CIVIL ENGINEERS.
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TRANSACTIONS.

No. 815.

THE POWER PLANT, PIPE LINE AND DAM OF THE PIONEER ELECTRIC POWER COMPANY AT OGDEN, UTAH.

By HENRY GOLDMARK, M. Am. Soc. C. E.
PRESENTED AT THE ANNUAL CONVENTION, 1897.

WITH DISCUSSION.

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It is proposed in the following paper to describe the works recently built in the cañon of the Ogden River, near the city of Ogden, by the Pioneer Electric Power Company of Utah, which con-

stitute the latest and most important hydraulic power plant of that State, and one of the largest works of the kind yet undertaken in this country. It is hoped that even an incomplete account of the designs and methods of construction adopted by the engineers of the above work may not prove without value in the planning of similar undertakings.

Location and Topography.—The city of Ogden is situated in the basin of Great Salt Lake, at an elevation of 4 300 ft. above sea level. It is about 13 miles east of that body of water, and 35 miles north of Salt Lake City. The limits of the city extend eastward to the base of the Wahsatch Mountains, which tower 5 000 ft. higher, reaching a total altitude of fully 9 000 ft. above sea level. This chain of mountains is intersected by numerous deep valleys or cañons, some of which rise abruptly, while others have a more gentle slope and form the outlet for drainage areas of considerable extent. Two such cañons, those of the Weber and Bear Rivers, are situated a few miles to the south and north of the city respectively, and are occupied by the Union Pacific and Utah Northern Railroads.

The cañon of the Ogden River is intermediate between the two last-named valleys, its outlet being directly east of Ogden and distant about 2 miles from the business center. It is a narrow, winding gorge, walled in by high and precipitous mountains, and presents a succession of scenes of romantic beauty unsurpassed in any other portion of the Rockies. The cañon is nowhere more than a few hundred feet in width at the bottom, and at some points it is so narrow that the construction of the excellent macadamized road that traverses it involved considerable rock excavation.

At a point about 6 miles above its mouth the narrow gorge through which the river flows widens out into a noble valley, some 8 miles long and 4 miles wide, surrounded by an almost continuous mountain chain. This valley contains several villages and many well-cultivated farms, and is traversed by three streams which unite at the upper end of the cañon, to form the Ogden River. A reference to the map, Fig. 1, will show clearly the course of the three branches, one of which drains the northern part of the valley, while another emerges from the mountains east of the village of Huntsville, and the third bisects the main range on the opposite side of the valley directly east of the head of the cañon.

The average annual rainfall in Ogden is 14 ins. In the Ogden Valley it has never been measured, but is probably twice as great. The drainage area is about 360 square miles. The flow of the river varies greatly in different years and at different seasons. In May and June, when the snow on the mountains melts, a maximum flow of 4 800 cu. ft.

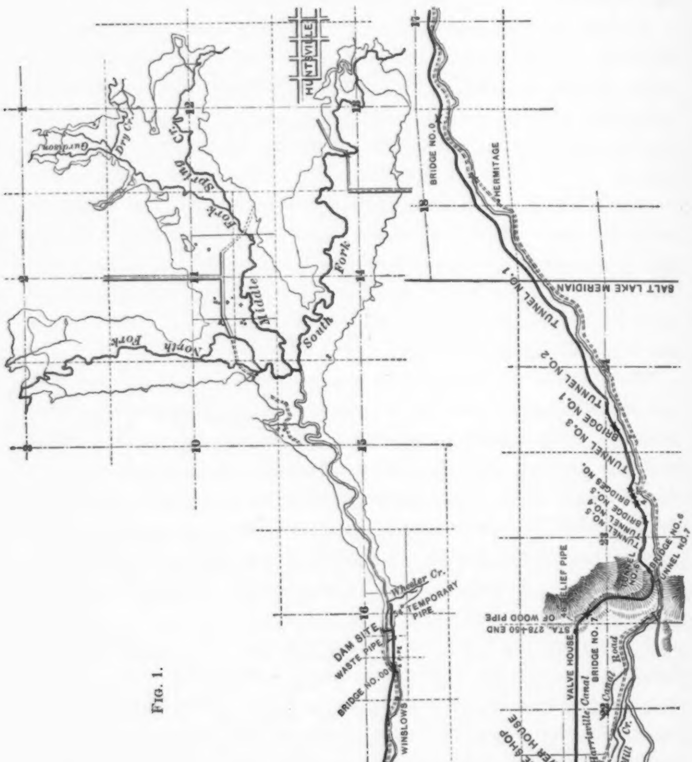

Fig. 1.

per second has been measured, while a minimum of 80 cu. ft. in August and September is also on record. The minimum in average years is fully 125 cu. ft. per second. In 1896 the flow did not go below 175 cu. ft. per second. This refers to the flow in the river-bed near the dam

site, but there is also considerable underflow in the gravel, as appears from the fact that the gauge readings several miles lower are always greater, though the affluents on this stretch are insignificant.

The slope of the stream in the upper valley is comparatively gradual, while in the 6 miles of the cañon there is a total fall of nearly 500 ft. This portion of the river has long appeared an attractive field for the development of power, but apart from a small saw-mill near its mouth there have been only abortive attempts made at utilizing the fall of the stream, and none of these earlier plants are now in operation.

The conception and successful completion of the works belonging to the Pioneer Electric Power Company are due mainly to the efforts of C. K. Bannister, M. Am. Soc. C. E., who, as chief engineer and secretary of the company, has devoted several years to the careful study of the engineering and financial problems involved. Preliminary surveys were made in 1894 and 1895, but it was not until the beginning of of 1896 that the location of the plant was definitely settled and actual construction begun.

General Description of the Works.

The plans of the Pioneer Electric Power Company contemplate the utilization of the waters of the entire Ogden River water-shed above the mouth of the cañon for the development of power as well as for irrigation. The central features of the plant are : A large storage reservoir and a masonry dam at the upper end of the cañon; a pipe conduit 6 ft. in diameter ; a power house containing water-wheels and electric generators. Besides this, there are electric transmission lines and substations for distributing the power to different points, and an extended system of irrigation canals.

The Storage Reservoir.—This will cover an area of about 2 000 acres, and will have a capacity of nearly 15 000 000 000 galls. It will be formed by building a dam across the cañon a short distance below its upper end. Little clearing will be necessary, but a considerable amount of farm land will be submerged, and a number of houses and barns will have to be vacated. A number of miles of highway will also be covered by water, and it will be necessary to build a wagon road of equivalent length on each side of the reservoir. This will involve heavy rock excavation, and will be expensive in construction.

The Dam.—The dam will be built of concrete masonry and founded on the bed-rock. Its length, measured on the crest, will be about 400 ft. It will be about 60 ft. high above the present river-bed, and the foundation will extend about 40 ft. lower, making a total height of over 100 ft. The sides and bottom of the cañon, at the site of the dam, consist of solid limestone rock, but the bottom is overlaid to a depth of about 40 ft. with coarse gravel containing a large amount of ground-water. A spillway for carrying off the flood waters is to be built on the north side of the cañon. The dam and spillway are more fully described in a following section of the paper.

A 9-ft. tunnel has been excavated through the solid rock around the south abutment of the dam, which, at ordinary stages of the river, will be the sole outlet for the water in the reservoir. It is to connect at its upper end to a masonry inlet-tower, with six 60-in. ports and sluice gates for admitting water.

About 100 ft. below the tunnel, and connected to it by a riveted steel pipe 8 ft. 6 ins. in diameter, the main gate-house is placed. This building contains two 72-in. valves, one of which serves for discharging surplus water, while the other connects with the main conduit.

The Main Conduit.—The main conduit is a pipe line with an internal diameter of 6 ft. Its total length is 31 600 ft., of which 27 000 ft. consist of wooden stave pipe, while the last 4 600 ft., at the lower end is riveted steel pipe. It is laid in a trench 8½ ft. wide, and covered with earth to a depth of 3 ft. on top. The wooden pipe is located on the side of the cañon with maximum horizontal curves of 14° and vertical curves of 8°, and follows the side of the mountain to a point about half a mile beyond the mouth of the cañon. The hydraulic grade line is assumed to fall at the rate of 0.2 per hundred, and the wooden pipe is kept close to, but below, this gradient, which begins at low-water level in the reservoir. The upper portion of the wooden conduit is mainly in earth excavation, but towards the mouth of the cañon the trench was excavated almost entirely in limestone and granite rock. There are eight tunnels in the rock, the longest of which is 667 ft. There are also eight steel bridges, with a total length of 560 ft., besides a timber trestle. The maximum hydrostatic head on the wooden pipe will be 117 ft., giving a pressure of 50 lbs. per square inch.

The Steel Pipe.—Steel pipe is used at the lower end of the conduit for pressures exceeding that mentioned above. It extends from the lower end of the wooden pipe to the power house, following an alignment which is straight in plan, but is adapted to the contour of the ground by fourteen vertical angles. Between these points the pipe is straight, the elbows being formed with radii of 30 ft.

The steel pipe is of 6 ft. diameter till it reaches a point 100 ft. above the power house. Here it divides into two branches, 54 ins. in diameter, which lead to two large receivers, one on either side of the power house building. The total hydrostatic head from the flow-line of the reservoir, when it is full, to the center of the receivers will be 516 ft.

The Power House.—This is built of pressed brick, with concrete and rubble footings, and cut-stone trimmings. Its outside dimensions are 135 ft. in length by 50 ft. in width. The roof trusses are of steel, and are supported on steel posts imbedded in the brick walls. The covering consists of standing seam steel roofing laid on a 2-in. sheeting of Douglas fir. A traveling crane of 15 tons capacity, operated by hand power, traverses the building, the track girders being carried by the steel posts. This building contains all the hydraulic and electric machinery used. A smaller, separate building serves as a machine and blacksmith shop.

Machinery.—The pipe line is calculated to deliver 250 cu.-ft. per second with a full reservoir, which corresponds to a velocity of flow in the 6-ft. pipe, of about 9 ft. per second. Taking the effective head at 440 ft., the gross available horse-power will be about 12 500.

The prime movers used are water-wheels of the impulse type, direct connected to electric generators. The complete plant will consist of ten water-wheels and dynamos, but only five are at present installed, although the power house building, the receivers, and the machine foundations, have been built in such a way that the whole number of machines can be erected at any time.

The water-wheels are of the Knight pattern, 58 ins. in diameter, with a capacity of 1 200 H.-P. each, at 300 revolutions per minute.

The dynamos are three-phase alternating-current generators. They give an output of 750 kilowatts at 300 revolutions per minute, and 2 300 volts continuously, with a frequency of 60 cycles per second.

There are two continuous-current exciters, direct connected with two 135-H.-P. water-wheels. Each exciter gives an output of 100 kilowatts at 550 revolutions per minute, and 500 volts continuously.

The arrangement of the wheels and generators is symmetrical on either side of the longitudinal axis of the building. There are two continuous foundations of concrete, and the central channel between them serves as a tail-race. After leaving the building, the water is carried back to the Ogden River by a channel, which is, in part, a covered flume, and partly an open ditch.

Of the machines at present installed, two of the wheels and generators are placed on one side, and three on the other. As the receivers, and in fact all portions of the plant, are in duplicate, the occurrence of an accident, which might cause a total stoppage of the plant, is almost wholly excluded.

In the gallery there are step-up transformers with a present capacity of about 3 000 H.-P. They receive the current from the generators at 2 300 volts, and raise the voltage to 16 100, at which pressure the current passes into the transmission lines.

The long-distance transmission lines are, at present, about 38 miles in length, extending to a substation in Salt Lake City. They deliver the current, at a voltage of 13 800, to the step-down transformers, which reduce it to 2 300 volts for local distribution. There are, besides this, wires for the local distribution of power in Ogden. The current in these lines has a voltage of 2 300.

The irrigation canals belonging to the company are situated near the shore of Great Salt Lake. The water from the pipe conduit, after leaving the power house, is allowed to run back into the natural bed of the stream, and is again taken out, at a point about five miles below, and diverted, so as to irrigate about 18 000 acres of land, not heretofore provided with water.

All portions of the plant are at present complete and ready for operation with the exception of the large dam and reservoir, the construction of which has not yet begun. A small crib dam with temporary headworks has been built a short distance above the site of the large dam, which gives the necessary head for filling the pipe, but does not provide for any considerable storage of water. A temporary stave pipe, 54 ins. in diameter, extends from the crib dam to the 9-ft. tunnel. In this way, the power plant can be operated and a consid-

erable amount of power generated prior to the construction of the large concrete dam.

Method of Doing Work.—The wooden and steel conduit was built by contract. The work done included not only the complete construction of all portions of the wooden and steel pipe line, but also all earth and rock excavation and tunnel work, as well as the masonry for bridges, culverts and retaining walls and the timber trestling. The steel bridges and the larger valves were purchased by the power company and erected by day labor. Smaller incidental work, such as the temporary headworks, etc., were built by day labor under the direction of the chief engineer, or let in small contracts. The power house and machine shop were built by contract, but the structural steel work was furnished by the company and the heavier girders erected by them. All the machinery was erected by the company by day labor, under the supervision of its engineers.

Detailed plans and specifications were made in the chief engineer's office of all parts of the work excepting the hydraulic and electric machinery, and the work of the different contractors was confined to carrying out the plans under the direction of the chief engineer and his assistants. In the case of the machinery, the specifications furnished to intending bidders gave the requirements and the general arrangement to which the designs would have to conform. They also included a statement of the tests to which the materials and the water-wheels and generators would be subjected before acceptance. The detailed planning of the machinery was, however, left to the companies which made the tenders.

The Conduit; its Hydraulics and Construction.

The conduit consists approximately of 5 miles of wooden stave pipe and $\frac{7}{8}$ mile of riveted steel pipe. The former is everywhere $72\frac{1}{2}$ ins. in internal diameter, while the latter has an average internal diameter of $72\frac{1}{4}$ ins., but varies slightly at different points. As a 6-ft. steel pipe is from three to four times as expensive per lineal foot as a wooden pipe of the same size, economy prescribed a location by which the length of the metallic conduit should be reduced to a minimum. Besides this, the capacity of the smooth stave pipe is considerably greater than that of the steel pipe, so that, from hydraulic considerations, the use of wooden pipe is preferable. For both of these reasons the cheaper pipe is

used from the dam to a point close to the power house. Its location is such as to reduce the pressure that comes upon it as much as possible without increasing the excavation unduly. Hence the wooden pipe line is built to conform to a hydraulic grade line of 2 ft. per thousand, a slope which is believed to correspond to the friction in the pipe. A large amount of curvature is introduced, but the radii are large, so that the obstruction to the flow is probably inappreciable.

From the end of the wooden pipe, the steel conduit runs direct to the power house. The slope of the steel pipe is quite steep, and the pressure is from 50 to 200 lbs. per square inch.

For moderate diameters the choice between cast iron and riveted steel pipes will usually depend on local conditions. For a 6-ft. pipe under such heavy pressures and at so great a distance to the nearest pipe foundries, the use of cast iron was entirely out of the question. The objections raised against the use of riveted conduits are their greater liability to corrosion and their smaller capacity, owing to greater frictional resistance. In the Ogden pipe great care was taken to prevent the rusting of the plates in transit and at the shops, and a coating of asphalt was afterwards applied by which a long life for the pipe is believed to be fully assured.

As far as the capacity of the pipe is concerned, late experiments leave no room for doubt that a riveted pipe will convey considerably less water under a given head, than a pipe with an unbroken, smooth surface. Just how much less will depend on the nature of the construction and of the coating, the size of the pipe and the slope of the conduit. The recorded data for the flow of water in pipes exceeding 4 ft. in diameter are very scanty, even for smooth internal surfaces. For riveted conduits there are almost none in existence. Various formulas are in use for computing the frictional resistances for new cases as they arise. The best of these are confessedly empirical, merely combining in a convenient shape the results of a number of measurements. When applying them to novel conditions, the results can be only approximate, though the designing engineer must fall back on such inductions in determining the size of conduits differing from previous examples. It is a cherished hope of the projectors of the Ogden pipe that it may furnish an opportunity for a series of careful experiments which may throw additional light on the flow of water in large pipes.

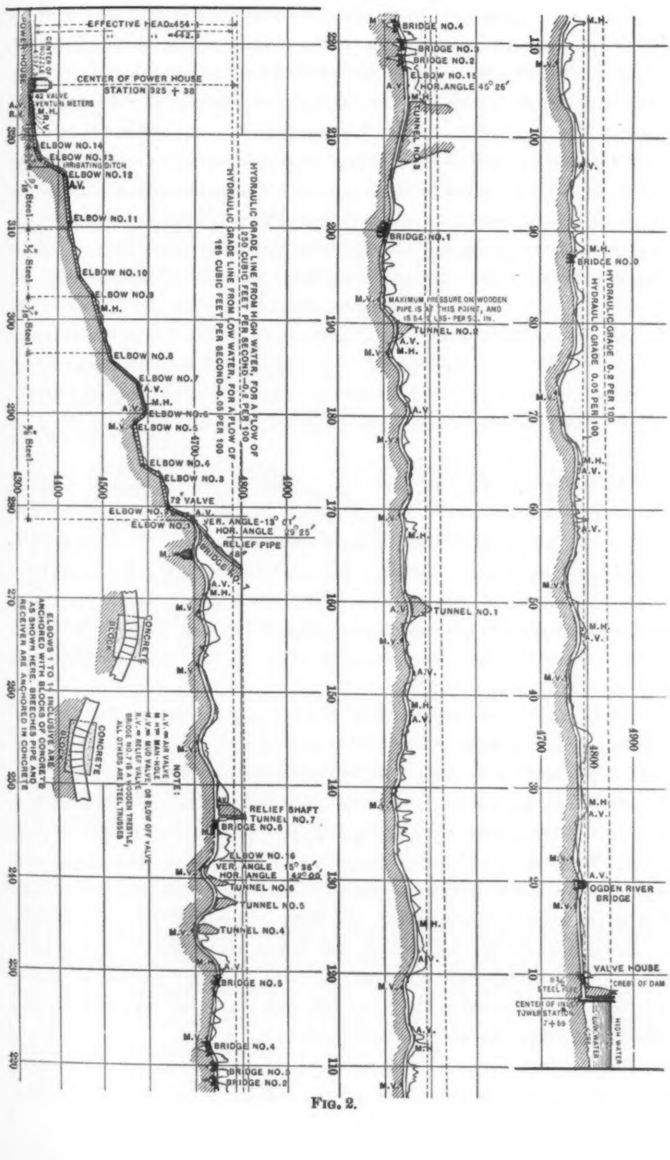

FIG. 2.

As appears from the profile (Fig. 2) and the preceding description, the Ogden conduit is compound, seven-eighths of its length being of wooden, and one-eighth of riveted steel, pipe. At the upper end the inlet will be funnel-shaped so that the coefficient at entrance will closely approach unity. The wooden pipe has an extremely smooth internal surface, absolutely without projections, and is continuous for its entire length, except at three points. These breaks consist of two riveted steel elbows and a short length of open tunnel. The elbows are of the same size and construction as the standard steel pipe. The radius of their central line is 30 ft., and the central angle about 45°. In Tunnel No. 7 the wooden pipe is omitted for a length of about 100 ft., and the unlined tunnel serves as a conduit. It is about 9 ft. square, and its surface is quite rough. The additional resistances at these three points will not, it is believed, absorb any considerable part of the head. The gate valves, when fully opened, will not obstruct the flow at all.

The surface of the steel pipe is very smooth, as the asphalt coating is glossy and continuous, with very few wrinkles. The obstructions to flow are the longitudinal internal butt straps and the rivet heads. The former are 16 ins. wide and $\frac{3}{8}$ in. and $\frac{1}{2}$ in. thick. They are continuous in almost all the sections, being exactly at the top of the pipe, so that they obstruct the flow much less than they would if breaking joint. The rivets have low, conical heads on the inside, which are smooth and regular in shape.

There are thirteen elbows of 30-ft. radius in the steel pipe, and one elbow of 40-ft. radius. From the end of the 6-ft. pipe, two $4\frac{1}{2}$-ft. branches about 100 ft. long lead to the power house.

If the 6-ft. pipe were open at its lower end, a straight line from the flow line in the reservoir to the end of the pipe would represent the hydraulic gradient. In that case, the greater part of the conduit would be above the hydraulic grade, so that air would be likely to collect at the high points and stop the flow. As actually used, the pipe is closed at its lower end, and the amount of water drawn off through the nozzles is comparatively small, so that a high pressure is maintained in the receivers. The hydraulic grade line, under these conditions, is at all points well above the conduit.

The problem, then, is to determine, for different amounts of water used per second, the proportion of the total head which will be ab-

sorbed by frictional resistances, and hence the pressure under which the water will be in the receiver at the lower end of the pipe.

The volume of water required to run the full plant of ten water-wheels will be 250 cu. ft. per second, which is equivalent to a velocity of $8\frac{3}{4}$ ft. per second in the 6-ft. pipe. The frictional resistances in the wooden and steel pipes for this velocity were computed separately and are given below.

Calculation of Friction Head.—If l is the length of pipe in feet, d is the internal diameter of pipe in feet, v is the velocity of flow in feet per second, g is 32.2, the acceleration of gravity, f is a coefficient that varies with d, v and the degree of roughness in the pipe surface, and h is the loss of head by friction, then

$$h^{*} = f \frac{l}{d} \frac{v^2}{2g}$$

In this case, for the wooden pipe, $l = 27\,000$ ft., $d = 6.03$ ft., $v = 8.75$ ft. per second.

Then for the smooth wooden pipe, and the above values of d and v, f can be taken as 0.01, and for a length of 1 000 ft. of pipe—

$$h'' = 0.01 \frac{1\,000 \times 8.75^2}{6.03 \times 64.4} = 1.97 \text{ ft.}$$

Hence the virtual slope of 2 ft. per 1 000, to which the wooden pipe is laid, will be sufficient.

In the Chézy formula ($v = c\sqrt{rs}$) the preceding result is equivalent to a value of

$$c = \frac{v}{\sqrt{rs}} = \frac{8.75}{\sqrt{1.51 \times 0.00197}} = 160.$$

This agrees closely with the value given for smooth pipes, under the same conditions, by Hamilton Smith, Jr., M. Am. Soc. C. E.†

In the Ganguillet and Kutter formula

$$v = \frac{41.6 + \frac{1.811}{n} + \frac{0.00281}{s}}{l + \left(41.6 + \frac{0.00281}{s}\right)\frac{n}{\sqrt{r}}} \sqrt{rs}$$

the value $c = 160$ is equivalent to a coefficient of roughness $n = 0.0104$.

Using the preceding value for h'', the total loss from friction in the wooden pipe is found to be $h = 27000 \times 0.0197 = 53.19$ ft.

For the riveted steel pipe, c in the Chézy formula may be safely taken at three-fourths the above value, or 120.

* Merriman's "Hydraulics," pp. 168–169.

† See his "Hydraulics." Table on p. 271.

The friction head in 1 000 lin. ft. of pipe will then be $h'' = 3.52$ ft., or, 16.19 ft. in 4 600 ft. of steel conduit.

For the whole pipe line the loss of head will be $53.19 + 16.19 = 69.38$ ft.

The difference in elevation between the flow line in the full reservoir and the center of the receiver is 516 ft., hence the efficient head is $516 - 69.4 = 446.6$ ft. This must be slightly reduced to allow for the Venturi meters and other specials.

Steel Pipe Construction.—The steel pipe conduit extends from the lower end of the wooden pipe at station 278 + 50 to the power house. Of this length, about 4 600 ft. consists of 6-ft. pipe and the remainder

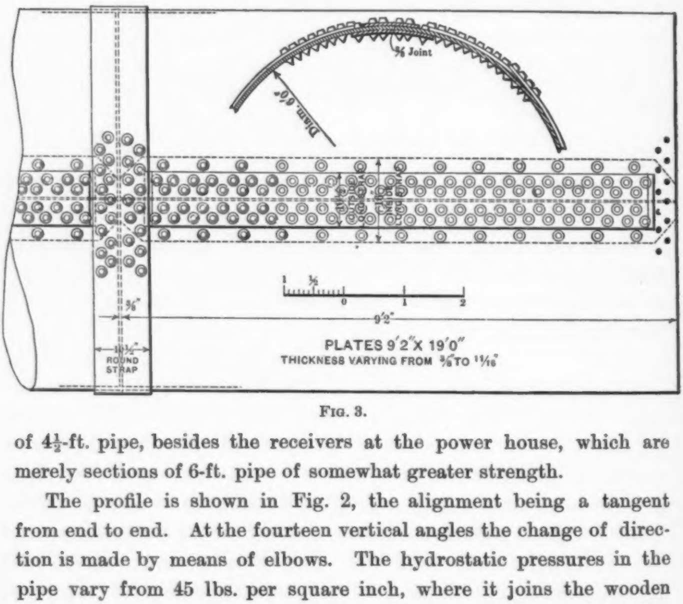

FIG. 3.

of 4½-ft. pipe, besides the receivers at the power house, which are merely sections of 6-ft. pipe of somewhat greater strength.

The profile is shown in Fig. 2, the alignment being a tangent from end to end. At the fourteen vertical angles the change of direction is made by means of elbows. The hydrostatic pressures in the pipe vary from 45 lbs. per square inch, where it joins the wooden pipe, to a maximum of 200 lbs. per square inch at the lower end. The size of the plates is the same throughout the straight part of the pipe, viz., 110 x 228 ins., giving sections 9 ft. 2 ins. long lengthwise of the conduit. There are 480 of such plates besides those used in the elbows. The thickness varies from $\frac{3}{8}$ to $\frac{11}{16}$ in., with increments of $\frac{1}{16}$ in., but the receivers are built of $\frac{7}{8}$-in. plate.

The internal diameter varies slightly with the thickness of the plates, which are uniformly 228 ins. long with $\frac{3}{8}$-in. joints.

Assuming the circumference at the middle of the thickness of each plate equal to 228.375 ins., which agrees closely with actual measurements, there results:

For $\frac{3}{8}$-in. metal an internal diameter of 72.32 ins.
" $\frac{7}{16}$-in. " " " 72.26 "
" $\frac{1}{2}$-in. " " " 72.19 "
" $\frac{9}{16}$-in. " " " 72.13 "
" $\frac{5}{8}$-in. " " " 72.07 "
" $\frac{11}{16}$-in. " " " 72.01 "

or an average diameter of 72.22 ins., if the lengths of conduit which are built of plates of different thicknesses are taken into account.

The construction of the pipes follows the usual practice of marine boiler work for high pressures. It is shown in Fig. 3. Extracts from the specifications are given in Appendix A.

The specifications for the steel were fully complied with, and the finish of the plates left nothing to be desired. The clause in the specifications limiting the excess in weights to 5% above the calculated weight, while requiring the plate to be practically of full thickness even at the edges, was doubtless too severe. In making these wide plates, the inevitable springing of the rolls made it impossible to keep the excess in weight down to the close limits permitted.

Another point in the specifications may be referred to, namely, the clause which requires that test pieces cut from finished plates of different thicknesses must show the same strength and ductility. While in this requirement the common practice of the past few years is followed, it is doubtful in the author's opinion whether it can be successfully defended. A tensile strength of 60 000 lbs. per square inch, with an elongation of 24% in 8 ins., corresponds in a plate $\frac{3}{8}$ in. thick to a carbon percentage of about 0.15, if basic open-hearth steel is used with phosphorus and manganese as specified. To obtain the same tensile strength and ductility in the $\frac{3}{4}$-in. plate rolled down from slabs or ingots of the same size, it is necessary to increase the carbon to fully 0.24. This means, of course, a much harder steel, which will be more subject to injury in subsequent processes of manufacture. The "rolling" of plates into cylindrical pipes causes severe strains in the metal, and experience has proved that much greater care is required in getting a perfect result in the thicker sheets. For this reason it

would be desirable to modify the specifications for plates so as to provide that the tensile strength required in the thicker plates should be less than in the thin ones. The chemical composition of the steel would then be more nearly the same, and the capacity of the heavier gauges for standing the necessary strains in the boiler shop would be increased.

Strength of the Riveted Steel Pipe.—The principal strain to which a water-pipe conduit is subjected is that due to internal fluid pressure. For pipes in which the ratio of the diameter to the thickness of the metal is considerable, this strain is given correctly by the simple formula of Mariotte. For pipes closed at the ends, there is a longitudinal strain in the plates composing the conduit. In any given case this unit strain will be only half as great as that which tends to burst the pipe. In a pipe bedded in earth this force is absorbed by friction, and its effect on the metal probably extends only a short distance from the closed end.

Differences in temperature and an unequal settlement of the conduit may also develop strains of considerable amount, which must be borne in mind when fixing the details of construction. Even more important is the possible action of collapsing strains, due to external air pressure, which may occur if the pipe is suddenly emptied by accident. It is hardly feasible to build a pipe of large diameter to withstand an external strain of this kind unless ample provision is made for admitting the outside air and preventing the formation of a vacuum. In the Ogden pipe a large number of valves and relief shafts are provided for this purpose, which are described in detail in a following section of the paper.

In fixing the thicknesses of the plates and the points on the profile at which they change, the unit strains on the gross section were taken at 12 000 lbs. per square inch in the $\frac{3}{8}$-in. sheets, decreasing to 11 000 lbs. for the $\frac{11}{16}$-in. plates.

The greatest head, h, to which any given thickness of plate was subjected, is shown in the following table :

$\frac{3}{8}$-in.	plate,	gross	strain	12 000 lbs.	per	square	inch,	$h = 288$ ft.
$\frac{7}{16}$-in.	"	"	"	11 800	"	"	"	$h = 330$ "
$\frac{1}{2}$-in.	"	"	"	11 600	"	"	"	$h = 371$ "
$\frac{9}{16}$-in.	"	"	"	11 400	"	"	"	$h = 410$ "
$\frac{5}{8}$-in.	"	"	"	11 200	"	"	"	$h = 448$ "
$\frac{11}{16}$-in.	"	"	"	11 000	"	"	"	$h = 484$ "

The net strains in the plates, the rivet stresses and the efficiency of the joints, that is, the ratio of the strength of the joint to that of the unpunched plate, are given below. The calculations will be understood better by referring to the details of the riveting shown in Fig. 3. The net section is taken between the rivet holes in the outer row of rivets, the pitch of which is twice as great as that in the other rows.

TRIPLE RIVETING, ZIGZAG; DOUBLE PITCH IN INSIDE ROW.

Plate, $\frac{11}{16}$ in. Rivets, $1\frac{1}{8}$ ins., cold; $1\frac{3}{16}$ ins., upset. Pitch, $3\frac{7}{8}$ ins.

Maximum tensile stress on plates, gross section....11 000 lbs. per square inch.
" " " net section......12 940 " " "
" shearing stress on rivets................. 5 740 " " "
" bearing " ....14 600 " " "
Efficiency of joint, 85 per cent.

Plate, $\frac{5}{8}$-in. Rivets, $1\frac{1}{8}$ ins., cold; $1\frac{3}{16}$ ins., upset. Pitch, $3\frac{7}{8}$ ins.

Maximum tensile stress on plates, gross section....11 200 lbs. per square inch.
" " " " net section.......13 200 " " "
" shearing stress on rivets................ 5 200 " " "
" bearing " " ....14 800 " " "
Efficiency of joint, 85 per cent.

Plate, $\frac{9}{16}$ in. Rivets, 1 in., cold; $1\frac{1}{16}$ ins., upset. Pitch, $3\frac{7}{8}$ ins.

Maximum tensile stress on plates, gross section....11 400 lbs. per square inch.
" " " " net section.......13 200 " " "
" shearing stress on rivets................. 5 520 " " "
" bearing " " ....15 800 " " "
Efficiency of joints, 86.2 per cent.

Plate, $\frac{1}{2}$ in. Rivets, 1 in., cold; $1\frac{1}{16}$ ins., upset. Pitch, $3\frac{9}{16}$ ins.

Maximum tensile stress on plates, gross section....11 600 lbs. per square inch.
" " " " net section.......13 600 " " "
" shearing stress on rivets................. 5 200 " " "
" bearing " " ....16 400 " " "
Efficiency of joint, 85.2 per cent.

Plate, $\frac{7}{16}$ in. Rivets, $\frac{7}{8}$ in., cold; $\frac{15}{16}$ in., upset. Pitch, $3\frac{9}{16}$ ins.

Maximum tensile stress on plates, gross section....11 800 lbs. per square inch.
" " " " net section.......13 500 " " "
" shearing stress on rivets................. 5 020 " " "
" bearing " " ....15 200 " " "
Efficiency of joint, 87 per cent.

Plate, $\frac{3}{8}$ in. Rivets, $\frac{7}{8}$ in., cold; $\frac{15}{16}$ in., upset. Pitch, $3\frac{9}{16}$ ins.

Maximum tensile stress on plates, gross section....12 000 lbs. per square inch.
" " " " net section.......14 000 " " "
" shearing stress on rivets................. 4 300 " " "
" bearing " " ....15 200 " " "
Efficiency of joint, 87 per cent.

Construction of Elbows.—The thickness of the plates in the elbows is the same as in adjacent straight sections. The change of direction between successive sections of an elbow was limited to 4° or 5°, so that each section is about 2½ or 3 ft. long. The maximum angle of any elbow was 45°, requiring nine or ten elbow sections. The butt straps, sizes of rivets and rivet spacing are the same as for straight pipe. Detailed drawings of all elbow plates were made in the chief engineer's office, by which all work in the shop was done.

Method of Construction.—All the work connected with the construction of the steel pipe sections was done at Ogden in a shop especially built and equipped with machinery for the purpose by the contractors. The principal reasons for adopting this plan were, first, the great saving in freight charges which resulted from being able to ship flat plates up to the full capacity of the cars instead of the finished pipe sections of which, for the lighter gauges, hardly half a carload could have been loaded on a standard flat car, and, second, that both work and inspection might be under the personal supervision of the chief engineer and his assistant on the pipe line. The contractor's works were erected near the lower end of the steel pipe line, on a spur track 3 miles in length, laid by the Union Pacific Railroad to connect with its main line. The boiler shop was a substantial frame building, covered with corrugated sheeting; it was 175 ft. long and 45 ft. wide, with a lean-to 40 ft. in width on each side. The railroad track passed through the building at one end and all material was unloaded under cover by a traveling crane which ran from end to end of the building, and, with several small jib-cranes, served to handle the work at the different machines. This crane was of 5 tons capacity; the traversing machinery was operated by electricity, while air hoists were used for lifting.

This building contained all the machinery required for punching, rolling, riveting and calking the pipe sections, and also the air compressor by which the field riveting and calking machines in the trench were driven. Two punches which were also used for shearing, a steam riveter, a set of 12-in. plate rolls, 120 ins. in length, and a 14-ft. planer for finishing the edges of plates and straps, constituted the larger machines installed. Besides this, there were three drilling machines, especially mounted for reaming rivet-holes, and some smaller shaping machines and lathes. Adjoining the main shop, a

blacksmith's shop, enclosed with corrugated iron, was built, in which the usual forges and furnaces for heating the rivets were placed, so as to reduce the fire risk of the larger and more inflammable building.

The construction of the shop was begun about May 15th, 1896, but there was some delay in the delivery of machinery so that the first plate was not punched till the middle of July. After this time until nearly the end of the year, work was pushed with two shifts of men, night and day and seven days in every week. It may be mentioned, in passing, that in September a violent wind storm overturned the main building, but fortunately did little damage to the machinery, so that the work was delayed only a few days.

The methods used were those of first-class boiler shops, and the work turned out compared favorably with the product of well-equipped eastern works. While it was not intended to increase the cost of the pipes unduly, the inspection was continuous and severe. The planing of butt straps and the reaming of the holes for $1\frac{1}{8}$-in. rivets, as required by the specifications, were strictly insisted upon, and the fitting was, as a rule, extremely good. The sections were riveted up complete in lengths of 9 ft. 2 ins., with a round-about strap riveted fast to one end, so that the field work was confined to making the connection between adjoining sections. The steam riveter used in the shop formed the heads by direct pressure and gave very good results. It was necessary, however, especially with $1\frac{1}{8}$-in. rivets, to hold on until the rivet head had cooled to a black heat.

Great care was taken with the caulking of the joints. It was done entirely on the outside straps by the use of split caulking machines driven by compressed air. The caulking was generally done while the section was suspended above the riveter, so that the outer row of rivets in the longitudinal butt-straps could be driven after the caulking was finished. The caulking of one edge of the round straps had, of course, to be done after the pipe was laid in the trench.

Dipping of the Pipe.—As soon as a section was completed, it was taken to the dipping tank adjoining the shop, which was equipped with a revolving derrick moved by steam power. The tank was circular, made of $\frac{1}{4}$-in. steel plates, and buried entirely below the ground. The mixture used consisted of C grade California asphalt, with the interstices filled with the best quality of natural liquid asphalt maltha,

not above 14° gravity Beaumé test. The mixture was melted and kept at a proper temperature by steam coils in the tank. It was found that a prolonged process of coating gave the best results, and for this reason nearly an hour was consumed in dipping each section, and gradually withdrawing it from the boiling mixture. The coating was smooth and glossy, and stood the necessary handling without much damage.

Erection and Riveting of the Steel Pipe in the Trench.—The riveting of a steel pipe line of the diameter and length of the Ogden pipe in the short period of time to which the contractor was limited presented many difficulties. For the $1\frac{1}{8}$-in. and even 1-in. rivets hand work was not practicable, and it was undesirable even for the $\frac{7}{8}$-in. rivets. Power riveters for this class of field work were almost if not quite untried, and there was little time for experiments. Two forms of power riveters were specially designed for the work, and all the rivets were driven with them, there being practically no hand riveting on any part of the pipe. They were both operated by compressed air which was drawn from a small pipe laid down on the edge of the trench for the entire length of the steel conduit. This pipe was 3 ins. in diameter where it left the compressor in the boiler shop, decreasing to 2 ins. at the upper end. The pressure used varied from 50 to 75 lbs. per square inch.

The first type of machine adopted by the contractors and used exclusively in the earlier stages of the work was designed by George H. Pegram, M. Am. Soc. C. E. The parts of the machine in the inside and on the outside of the pipe are entirely distinct. The former consists of a pressure cylinder and piston, the axis of which coincides with the central line of the pipe, and a framework with a toggle-joint. By means of this the thrust of the piston is turned through 90°, so as to form the heads of two rivets diametrically opposite each other on the inside of the pipe. The cylinder revolves freely on its axis and can be rotated so as to drive in succession all the rivets in a given row. It is supported by means of springs on a low iron truck with wheels, running on a short track which rests on the bottom of the pipe. This machine acts by direct pressure like the steam riveting machines commonly used in boiler and bridge shops.

The portion of this machine outside of the pipe consists essentially of a heavy cast-steel ring which furnishes the necessary reaction against

the thrust of the riveting machine inside. For this purpose four cups, adjusted by means of hand-wheels, are attached to the large ring at points 90° apart. The ring hangs from a framework above, which travels on a timber runway supported on the top of the pipe. Gearing is provided for traversing the entire frame, as well as for revolving the ring around the axis of the pipe. When in operation, two rivets are inserted from the outside into holes diametrically opposite; the ring is moved so that two of the cups come exactly opposite the rivets. The hand-wheels are then screwed down and pressure is applied from the cylinder within. All the rivets in a row are driven with one setting, but when a joint is completed the entire machine must be moved ahead, which, for so heavy an apparatus, is rather slow work. About 500 rivets have been driven in a day of ten hours with this machine.

The second type of riveting machine used is much lighter than the one last described. The heads are not formed by steady pressure, but by striking a large number of blows in rapid succession. A frame work encircles the pipe and sustains the internal reaction; it revolves on the pipe on special cast rollers. One rivet only is driven at a time, the head of which is formed on the inside of the pipe. There is an air cylinder with a piston which is moved forward after the rivet is inserted, so as to hold it in place and sustain the blows of the percussion riveter within the pipe. The latter is comparatively light so that it can be handled by only two men working inside of the pipe. It consists of a small air cylinder, similar to that of a percussion rock-drill, the piston-rod of which has a cup at its outer end. This contrivance is held in place by a heavy rod, fastened into a rivet hole diametrically opposite the rivet to be driven.

The operation is similar to that of the Pegram riveter, and the number of rivets driven per day is about the same. Owing to its greater lightness, the number of men required to handle this machine is considerably less, thus reducing the cost of driving a rivet.

The quality of the work appears to be entirely satisfactory, although for driving the $1\frac{1}{8}$-in. rivets, in the $\frac{11}{16}$-in. plates, a somewhat heavier machine would be preferable.

Erection.—The trench in which the steel pipe was laid was almost everywhere accessible by team, and the sections were distributed in this way. At convenient points, a number of lengths were unloaded

and a sloping runway cut out, along which the sections were skidded into the ditch. A short length of light railroad track was commonly built along the center of the trench on which the sections were transported to connect with the finished ends.

The riveting machines used made it necessary to excavate below the pipe to an additional depth of about 3 ft. so as to allow the framework of the riveter to pass. The sections were supported on timber blocking placed from 5 to 9 ft. apart. This blocking consisted of 6 x 6-in. timbers, from three to six pieces being laid one on top of the other. The engineer's grade stakes were generally set with their tops a multiple of 6 ins. below the bottom of the pipe, so that the foreman knew just how many timbers were needed at any point to give correct grade.

The joining of the sections was readily made and the practice was to keep the erecting gang a number of sections ahead of the riveting machines, so that both riveting and erection could proceed uninterruptedly. At the beginning of the work much difficulty was met with in building the pipe to a straight line, as it showed a decided tendency to assume a vertical curve which threatened to bring the pipe to the center of the earth instead of the top of the hill side. The exact cause of this distressing phenomenon was the subject of much discussion, but was never fully settled. As a matter of fact, after the men became more experienced and greater care was taken with the blocking, the difficulty disappeared, and the foreman finally became quite expert in giving the pipe any desired elevation or direction. The elbows and tangents fitted the ground almost perfectly, and of about 500 plates ordered not a single one was spoiled, either in the shop or field.

Testing the Pipe.—When the first ten sections of $\frac{11}{16}$-in. pipe were riveted up in the trench, making a total of 92 ft. of completed pipe, they were closed at each end by dished heads, which were bolted fast and caulked with lead. The pipes were filled with water and subjected to hydraulic pressure. For this purpose the air compressor was speeded up so as to give a pressure of 200 lbs. per square inch, which was maintained for twelve minutes, when it was stopped from fear of injuring the rather light compressor used. While the compressor was at work, the pressure was raised to 250 lbs. per square inch at intervals by a hand-pump. This last increment of pressure was applied as a jerk or kind of water-hammer, so that as a test it was doubly severe.

Under this pressure the pipe proved to be very tight. Out of some 3 000 rivets, only twenty-two were discovered that leaked at all, and most of these merely sweated. The caulked joints were also practically tight, showing only a few slight leaks. These sections were the first built. The later work would probably, if tested in like manner, have given even better results.

Anchorages.—The profile of the steel pipe line shows that it contains some steep grades. It was deemed advisable to hold the pipe at these places by building anchorages around it at the angle points. These anchorages consist of concrete blocks, about 8 x 10 ft. in section and about 10 ft. long. They were built in timber molds. The mixture consisted generally of Portland cement, sand and crushed stone, in the proportions one, two and five.

Back-Filling.—It was originally intended not to cover up the steel pipe until after it was completed and filled with water, but as the work progressed it was found that the effect of the differences in temperature made it desirable to put in the back-filling sooner. The earth was, therefore, shoveled under and around the pipe, filling the trenches and covering the pipe about 3 ft. on the top. The filling was, of course, carefully tamped. The effect of temperature on the pipe was twofold. When there was bright sunshine on the top of the pipe, the bottom remaining in the shade, the exposed side was elongated, so that the pipe line became curved, and in one case was observed to lift from its supports for a distance of over 100 ft.; besides this, there was considerable expansion and contraction longitudinally, as well as a change in the diameter of the pipe. As a consequence, the pipe shrank away from the concrete in the anchorages, leaving openings which, in some cases, were as large as half an inch. Several of the concrete anchorages also showed a number of fissures and cracks, both on top and on their sides.

Weights and Lengths of Steel Pipe.—There are 476 regular sections of straight 6-ft. pipe, besides the 14 elbows. The lengths and weights are given in Table No. 1, calculated on a basis of 490 lbs. per cubic foot. The invoice weights were about 6% greater.

Wooden Stave Pipe.—The wooden stave pipe is of the type successfully used in the West for many years. It is believed, however, that its diameter of 6 ft. is greater than that of any conduit of the kind previously built. A new departure, too, is the use of Douglas fir in

place of California redwood. The former timber is much harder and stiffer, and some trouble was anticipated in its use for staves, especially in view of the great amount of curvature in the pipe line. After the first few days, however, no great difficulty was experienced in putting the staves together properly, even on the 14° curves.

The lumber was furnished by Oregon and Washington mills, being planed on all sides to a uniform finished size of 8 x $2\frac{1}{2}$ ins. before shipment. The specification was a severe one, requiring the best class of timber, perfectly free from knots, sap holes, season-checks and other flaws. It was carefully inspected at the mills, and again after delivery

TABLE No. 1.—Weight of Steel Pipe. Pounds.

Number of sections.	Thickness of plate. Inches.	Length. Feet.	Weight of main plates.	Weight of longitudinal straps.	Weight of roundabout straps.	Total weight, plates and straps.	Weight of rivets.	Grand total.	Weight per lineal foot.
186...	$\frac{3}{8}$	1 711.2	495 876	57 846	52 200	605 922	45 019	650 941	380
66...	$\frac{7}{16}$	607.2	205 260	20 526	21 600	247 386	16 415	263 801	434
79...	$\frac{1}{2}$	726.8	280 766	24 569	29 550	334 885	29 120	364 005	500
70...	$\frac{9}{16}$	644.0	280 000	21 770	29 430	331 200	24 275	355 475	552
29...	$\frac{5}{8}$	266.8	128 818	12 006	13 560	154 384	14 184	168 568	632
46...	$\frac{11}{16}$	423.2	224 620	19 044	25 180	268 844	23 637	292 481	691
476...	....	4 379.2	1 615 340	15 761	171 520	1 942 621	152 650	2 095 271	478

Divided as follows: Main plates, 77% or 100%
Straps, 15% 20%
Rivets, 8% 9%
100% 129%

14 elbows in 6-ft. pipe.	71 231	6 144	17 628	95 003	11 593	106 596

The $8\frac{1}{2}$-ft. pipe near the dam, the $4\frac{1}{2}$-ft. pipe at the power house, and the receivers raised the total weight of the steel pipe to over 2 500 000 lbs.

at Ogden. The lumber used was almost beyond criticism, being practically perfect in appearance. It was, as far as possible, thorougly seasoned and dried and was kept under cover at Ogden until it was placed in the trench.

The pipe was built of thirty-two staves, the finished staves being $7\frac{1}{2}$ ins. wide on the outside, $7\frac{1}{8}$ ins. wide on the inside, and 2 ins. in thickness. A planing mill for the work of building the wooden pipe was especially erected near the mouth of Ogden Cañon. In this mill both sides of the staves were dressed in a planing machine to conform to the outlines of a circle; the outside to a circle of $38\frac{1}{4}$ ins. radius, and the inside to a circle of $36\frac{1}{4}$ ins. radius.

The radial surfaces were planes, smoothly finished. Steel templets of the stave section were furnished to the contractor and the inspectors, and no stave varying more than $\frac{1}{32}$ in. was accepted.

According to the specifications, the lengths of the staves were to be 16, 18, and 20 ft., but not more than 15% of 16-ft. lengths, nor more than 30% of 18-ft. lengths, were allowed. This condition was fully complied with, and many lengths of 24 ft., 26 ft., and even more, were used.

In building the pipe the staves were selected so as to break joints at least 12 ins., and at all end joints a steel tongue was placed, being fitted into grooves sawed into the ends of the staves. These grooves had a depth equal to half the width of the tongue, and were of such width that the tongues fitted tightly. The tongues were $1\frac{1}{2}$ ins. wide, about $\frac{1}{8}$ in. thick, and somewhat longer than the width of the staves, so as to extend $\frac{1}{8}$ in. into the two adjoining staves. Experience in previous conduits has shown that this construction is sufficient to make a tight joint at the ends of staves. The radial edges of the staves are perfectly plain, without the beading sometimes used, dependence being placed on the swelling of the timber for producing a tight joint.

Sills.—At intervals of 8 ft. throughout the length of the conduit, sills 6 x 8 ins. and 8 ft. long were laid in the trench with the 8-in. side down, at right angles to the center line of the pipe, with chocks cut to fit the periphery of the pipe at each side and fastened on top of each sill by a boat spike. An additional brace of 2 x 4-in. timber was placed at an angle of 45°, and also spiked to the sill. These sills were bedded as exactly as possible, according to the engineer's lines and grades, and proved a sufficient guide for placing the pipe in its proper position.

Bands.—Many different methods for banding stave pipe have been proposed from time to time, but only a few of them have had the test of practical experience. In the early pipe lines, bands similar to those used on barrels were employed, but the use of round rods of steel has now become universal for all but the smallest sizes. There are, however, many different forms and details for connecting the rods and making the necessary adjustments.

On the Ogden pipe the bands consist of round steel rods of $\frac{5}{8}$-in. and $\frac{3}{4}$-in. diameter, the latter being used only where the pressure exceeds that due to a head of 100 ft. They were made of tested steel, having an ultimate strength in tension of between 55 000 and 65 000

lbs. per square inch, an elastic limit of 40 000 lbs. per square inch, and an elongation of 25% in 8 ins. The percentage of phosphorus was not to exceed 0.095, and of sulphur 0.075. Each rod was to bend cold through 180° upon itself without sign of fracture.

A complete band consists of two rods bent to a semi-circle and two steel shoes. Their shapes and sizes are represented in Fig. 4. There are two kinds of rods, one of each kind being required to make a complete ring or band. The first kind has a loop eye at each end and was made of one piece of steel without welds, except in the loops. The

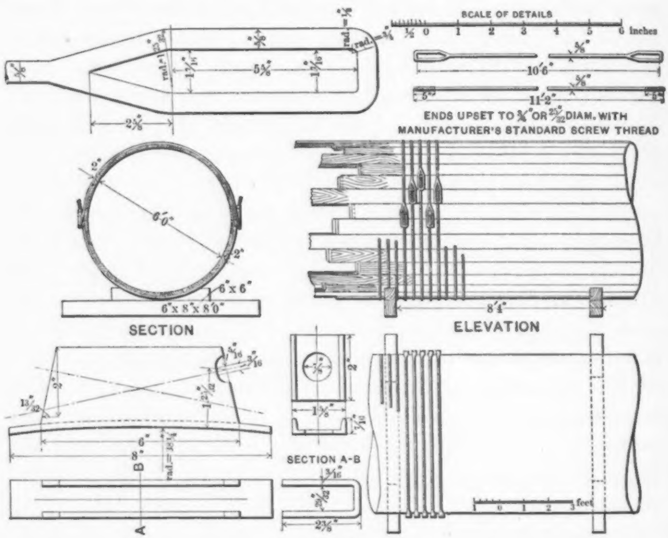

FIG. 4.

second kind of rod has two upset screw ends made without welding. All nuts were at least $\frac{7}{8}$ in. thick, and of such close fit that with clean threads they could not be turned with the fingers. The shoes are also shown in Fig. 4, together with the method of adjusting the rods and shoes. They were pressed when hot out of $\frac{3}{16}$-in. steel and have proved quite satisfactory during the construction of the pipe, though a slight increase of the thickness of metal would probably be an improvement. The form of shoe and rods was designed by Mr. J. C. O'Melveny, of Ogden.

The bands are placed perpendicular to the end of the pipe with the shoes at the sides and spaced according to the instructions of the engineer. It was desired to subject the bands, as far as possible, to the same maximum unit strain in all portions of the conduit. For this purpose a table was prepared giving the number of bands to be used in each 100 ft. of pipe and their average distance apart. Where there was much difference in the pressure within the limits of a 100-ft. section, the spacing was changed at the + 50 point, and in some cases a different spacing was used in every 25 ft. of length.

The working stress of a $\frac{5}{8}$-in. rod was taken at 4 500 lbs., and of a $\frac{3}{4}$-in. rod at 6 500 lbs., giving a unit strain of 14 660 lbs. per square inch of metal. The spacing was, of course, proportioned in accordance with the head at each point, the whole water pressure being supposed to be carried by the bands, as no allowance was made for any stiffness of the staves.

The following simple formula was used in the computations, the diameter of the pipe being taken as 6 ft., in which H is the effective head in feet at any point, N is the number of bands required for a length of 100 ft.

$$\text{Then, for } \tfrac{5}{8}\text{-in. bands, } N = \frac{H \times 62.5 \times 6 \times 100}{4\,500 \times 2} = 4.16\,H$$

$$\text{and for } \tfrac{3}{4}\text{-in. bands, } N = \frac{H \times 62.5 \times 6 \times 100}{6\,500 \times 2} = 2.9\ \ H$$

When the reservoir is full, the least static head on any point of the wooden pipe will be 55 ft. and the greatest 117 ft. Five-eighths-inch bands are used for heads up to 100 ft., and $\frac{3}{4}$-in. bands for greater pressures. The spacing for the $\frac{5}{8}$-in. bands varies from $5\frac{1}{4}$ down to $2\frac{7}{8}$ ins., changing by differences of a $\frac{1}{4}$ of an inch between $5\frac{1}{4}$ and 4 ins., and by differences of $\frac{1}{8}$ in. between 4 and $2\frac{7}{8}$ ins. The spacing of the $\frac{3}{4}$-in. bands is 4 ins. for 100 ft. head, which is gradually reduced by differences of $\frac{1}{8}$ in. to a minimum pitch of $3\frac{1}{2}$ ins. By this arrangement the strain on the metal comes within 3% of being the same on all the bands used.

The only other detail that calls for comment is the connection of the wooden and the steel pipes. As shown in Fig. 5 all parts are of rolled steel. The steel pipe enters into the stave pipe for a length of 12 ins., and is securely bolted. Besides this, there are two angle flanges, one of which is riveted to the steel pipe, while the other con-

sists of loose angle irons fastened by bolts. There is a packing of tarred burlap between the steel rings and the staves. Six connections of this kind are used in the main pipe, one each at the upper and lower ends, and the others at two points, where the alignment made it necessary to use steel elbows.

Erection.—The light weight of the separate staves and bands makes stave pipe specially adapted for cañon work. In the upper part of the valley, the line was easily reached with teams. Further down it is less accessible, and at the mouth of the cañon a cable-way about 1 000 ft. in length supported on framed towers, was built, by which a large amount of material was raised. The hoisting engine, the lifting capacity of which was about a ton, was placed at the bottom. The incline described later in connection with the bridge work also served

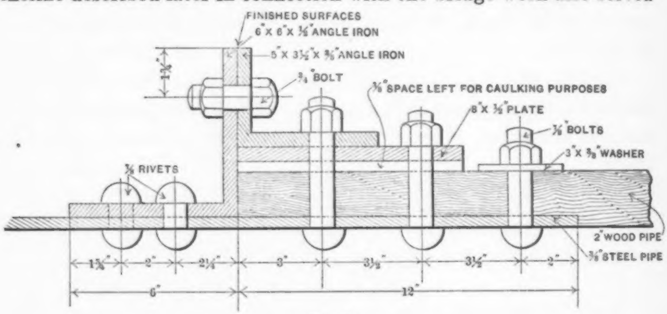

FIG. 5.

to take up pipe material. A light track, laid in the trench, was used for distributing the staves and bands.

The building of the pipe proceeded at a number of different points simultaneously, and at one time there were seven separate gangs at work, laying as much as 500 lin. ft. per day. In the lower portion it was not possible to work at more than two or three places. Each gang consisted of about twenty men; about half of these were engaged in putting the staves together, using only enough bands to keep the pipe in place. The rest of the men followed, and put on the full number of bands. They were cinched back afterwards several times with short wrenches, so as to obtain a proper amount of tension without crushing the fiber of the wood.

The vertical curvature was obtained by building the pipe on the sills, properly set beforehand, but where there were sharp, horizontal

curves, it was necessary to spring the partly banded pipe by means of jacks. It was then held in place by blocking, and, after being full banded, showed no tendency to return to a straight line. In assembling the staves, a bent piece of 2-in. pipe was used as a templet, but the vertical diameter was made slightly greater than the horizontal to allow for settlement.

The whole pipe, except the parts in the tunnels and on the bridges, was covered with earth to a depth of 3 ft.

The amount of lumber used was about 1 500 000 ft. B. M., and the total weight of steel in bands and shoes about 2 500 000 lbs.

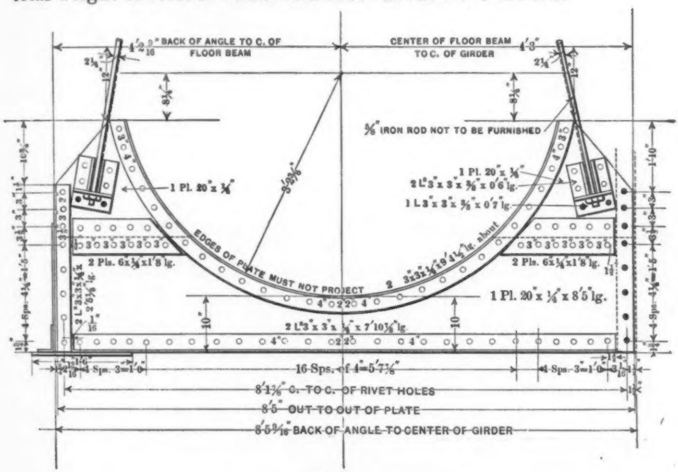

FIG. 6.

Bridges.—There are nine bridges on the line of the pipe, of which one is a timber trestle, while the rest are built of steel. Besides these, all of which carry the wooden pipe, there are a few short culverts under both the wood and the steel pipes.

The longest span is the bridge which carries the pipe over the Ogden River, at the only place where the conduit crosses that stream. This bridge is a riveted bowstring girder 75 ft. in length. The top chord forms the segment of a circle, with a 75-ft. radius, while the lower chord is bent to an arc corresponding to a vertical curve of 6°. The floor beams are attached to verticals 4 ft. 3 ins. apart. The distance between centers of girders is 8 ft. 6 ins.

The other bridges carry the pipe line over lateral ravines, or else were built in place of masonry retaining walls at points where a steel structure was cheaper. They are all riveted girders with a single Warren system of bracing and vertical end posts. The floor beams are shown in detail in Fig. 6. They are fastened to vertical angles at every 4 or 5 ft., so as to support the stave pipe at frequent intervals. The distance between girders is 8 ft. 6 ins. throughout.

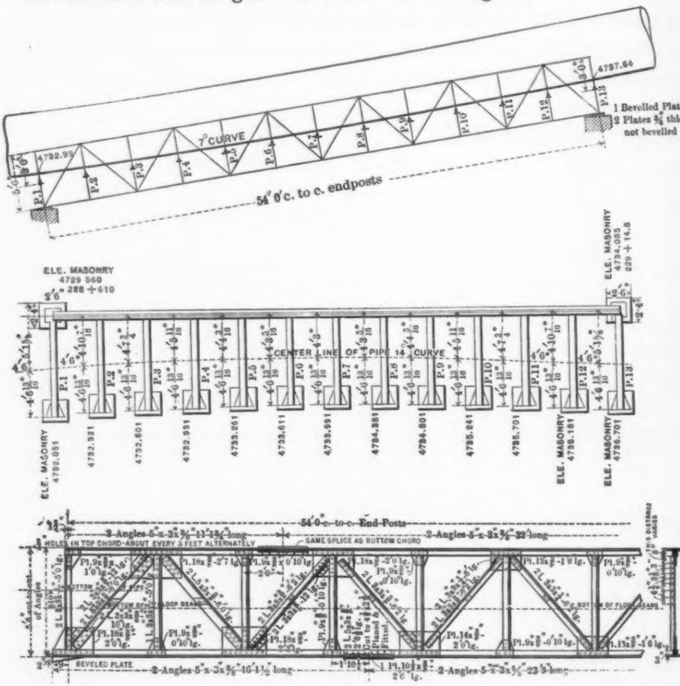

FIG. 7.

Bridges 2, 3, 4 and 6 consist of two girders supported on masonry abutments. The only interesting feature in their construction arises from the fact that the pipe line is built with vertical curvature, so that the floor beams had to be placed at different elevations. The tops of the abutments were therefore placed at such an elevation that a straight line connecting the bed plates is parallel to the chord of the vertical arc. The offsets from this chord were then computed for

every floor beam, and the position of the connecting bolt holes in each vertical post of the girders determined accordingly. The floor beams themselves remained the same for these four spans.

The line at bridge 5, Fig. 7, is in rock and on a side hill. At the center line of the pipe the surface of the ground is at nearly the same level as the bottom of the pipe, sloping at an angle of 50° to 80° at either side. A masonry retaining wall would have been 20 or more feet in height, with considerable rock excavation in the foundation. It was, therefore, decided to use a steel construction instead. The latter consists of a single girder 55.5 ft. long over all, with its ends resting on abutments, and of floor beams that carry the pipe; they have one end bolted to the girder, the other end being supported directly on the rock or on small, separate piers or low walls built on the rock.

On this bridge the line of the pipe follows a 7° vertical and a 14° horizontal curve. In order to conform to the curved horizontal alignment, it was necessary to vary the construction of each floor beam, as the center of the pipe support had to be placed at varying distances from the girder. The vertical curvature was maintained by varying the points of attachment of the floor beams to the girders, as described above.

Bridge 0 consists of two spans 34 ft. each, and is of the same type as bridge 5.

Bridge 1 is a steel trestle, 136 ft. 7 ins. long, consisting of three spans of 33 ft. $3\frac{1}{2}$ ins. and two braced towers of 18 ft. $3\frac{1}{2}$ ins. The end spans are supported on masonry abutments, while the tower posts rest on low piers.

Detailed plans showing all dimensions were made, and bids asked for per pound of finished bridge work, f. o. b., Chicago.

In calculating strains, the following loads were used:

Weight of water in pipe,	1 850 lbs.	per lineal foot.		
Weight of wooden pipe,	350	"	"	"
Total..........	2 200	"	"	"

The weight of the steel work was 250 to 300 lbs. per lineal foot. The unit strains used were 13 000 lbs. per square inch net in tension, and about 8 000 lbs. per square inch in compression.

Basic open-hearth steel was used, which, when tested in sample bars 2 ins. wide and 10 ins. between grips, met the following requirements:

Ultimate strength...54 000 to 62 000 lbs. per square inch.
Elastic limit ....31 000 lbs. per square inch.
Elongation in 8 ins..24 per cent.
Reduction of area...48 "
Also the usual bending and drifting tests.

All mill and shop work was inspected, the usual specifications for the best class of punched work being followed; but the holes for all field connections were drilled to fit turned bolts.

Erection of Bridges.—The bridges over Ogden River and bridge 0 were close to the highway and readily accessible. The other spans were located in the rocky part of the cañon, from 200 to 500 ft. above the bottom. The side slopes were too steep for building a wagon road, so that it became necessary to adopt some other means for handling the material. An inclined plane was therefore built opposite bridge 1. It consisted of a light timber trestle work which crossed the river and followed the sloping rock close to the ground at an average angle of fully 45°. Ties were placed about 3 ft. apart, and a light steel railroad track laid on them.

The cars containing the material were hoisted by means of a $\frac{5}{8}$-in. steel wire cable which passed around a sheave securely anchored at the top. Two horses working a sweep at the bottom were sufficient to raise a maximum load of 3 000 lbs. The empty cars were lowered by braking. The whole contrivance cost only a few hundred dollars, but served to hoist most of the bridge steel, besides a large amount of stave lumber and bands for the wooden pipe. The steel for bridge 6 was hoisted by the cableway elsewhere referred to.

After it was hoisted to the top the material was distributed by cars moved by mules along the light railway track which was built for the wood pipe construction. This was rather tedious work, owing mainly to the sharp curves in the line. The short girders 18 and 34 ft. long, came from the shop in one piece, but the longer, 55-ft. and 70-ft., girders were shipped in three pieces.

For erection, light, but well-braced, timber falsework was used, which, in some places, was 30 to 40 ft. high and rested on the rock below. Owing to its steep slope, it was not easy to find a good support for the bottom sills, and for one or two bents recourse was had to blasting. The total cost of erection, considering the light character of the work, was not excessive, being barely more than 1 cent per

pound. There was, however, no field riveting, as turned bolts were exclusively used.

The erection was done by the Pioneer Electric Power Company by day labor, as the steel bridges were not included in the pipe line contract.

Timber Trestle.—This trestle is also on the wooden pipe line, but close to its junction with the steel pipe. The material used was Douglas fir, with the sills resting on masonry piers.

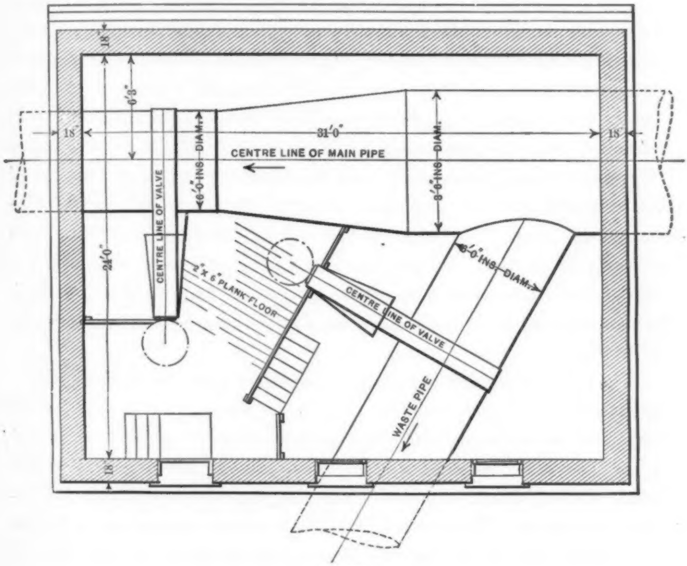

FIG. 8.

Masonry Abutments and Piers.—The abutments and piers for the bridges were built of rubble masonry laid in cement mortar. The stone was quarried close to the bridge sites, and consisted of unsquared stones. No attempt at regular courses was made, but the stones were selected and laid so as to break joints horizontally and vertically. English or German Portland cement was used for mortar in the proportion of one part of cement to three parts of sand. The exposed surface joints were pointed with cement mortar, and no projecting points or irregular edges were allowed.

Valves and Other Specials.—Between the inlet tower at the dam and the power house there are five large gate valves, besides the smaller blow-off and relief valves. Three of these valves are 72 ins. in diameter, and the other two 42 ins.

Two of the 72-in. valves are placed in the gate-house just below the dam, shown in Fig. 8. These two valves are identical in construction. They are horizontal valves, with double gates. There are two separate stems which are geared together and are operated by a hand-wheel. As the gates of these valves are very heavy, each gate has two bronze disks or wheels placed on the lower side, preceded and followed by a solid bronze scraper or track cleaner. These wheels run on a bronze track fastened to the case of the valve, and the scraper coming close to the tracks keeps them clear of mud and other obstructions, and allows the wheels to hug the track closely and prevent the binding of the gates. These valves were designed to withstand a maximum water pressure of 25 lbs. per square inch and weigh about 22 000 lbs. each. As the gate-house was nearly 7 miles from the end of the side track, they were shipped in sections and put together on the ground. Although the manufacturers feared that the valve seats might be injured in transit, it is believed that no damage was done, and the gearing was satisfactorily adjusted.

The third 72-in. valve is placed near elbow 2 of the steel pipe line, about 100 ft. below its junction with the wooden pipe. Its purpose is to permit the closing of the wood pipe, so that it can be kept full of water even when the steel pipe is empty. The hydrostatic head at this point is nearly 200 ft. The valve was designed for a pressure of 100 lbs. per square inch. The construction of a valve of this size and pressure was almost unprecedented. In general arrangement, it is similar to the lighter valves previously mentioned, but all parts are, of course, much heavier, and there is only a single valve stem. It has a 12-in. by-pass, and is operated by a hydraulic lift supplied with pressure water from the main pipe above the valve.

It is 8 ft. high, and 4 ft. from face to face of flanges, and its extreme length, including the flanges, is 24 ft. 6 ins. The hydraulic lift cylinder is lined with bronze to prevent corrosion, the spindle within it being steel with a bronze casing $4\frac{1}{2}$ ins. in diameter. The valve stem proper is made of the best bronze. This valve is fitted with the bronze scraper wheels and track already described.

The site of this valve was only three-quarters of a mile from the railroad siding, but fully 300 ft. above it, and accessible only by such temporary roadways as had been constructed for building the pipe line. The total weight of this valve is 52 000 lbs. It was, of course, shipped in sections, but it was found impossible to reduce the weight of the heaviest single piece below 20 000 lbs. Transporting such large masses was, of course, slow and difficult, and twenty-four horses were required to move the heaviest piece. The valve was, however, safely transported and put together without accident. It is believed to be the heaviest valve yet built.

The foundations for these valves were concrete blocks, carried down

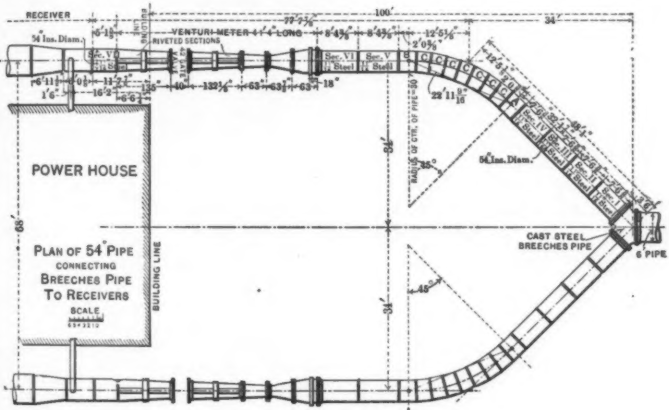

FIG. 9.

3 to 5 ft. to a solid gravel bottom. They were made wide enough to support the ends of adjacent pipe sections, so as to relieve the cast-iron end flanges of the valves of strain. The permissible pressure on the soil was taken at 1 000 lbs. per square foot.

Besides these large valves, there are two smaller ones 42 ins. in diameter, which are placed between the lower end of the 6-ft. pipe and the power house on the two branches that lead to the receivers. These branch pipes are 54 ins. in diameter, their general construction being the same as that of the larger pipes. They are reduced to 42 ins. by the introduction of the Venturi meters, thus permitting the use of the smaller valves. These valves were tested to 400 lbs. pressure

per square inch. Their general arrangement is the same as that of the larger valves. They have two separate stems and are moved by hand gearing.

The connection between all the valves and the steel conduit is made by weldless, rolled steel angle flanges. One leg is riveted to the pipe by a double row of $1\frac{1}{8}$-in. rivets, and the other is bolted to the

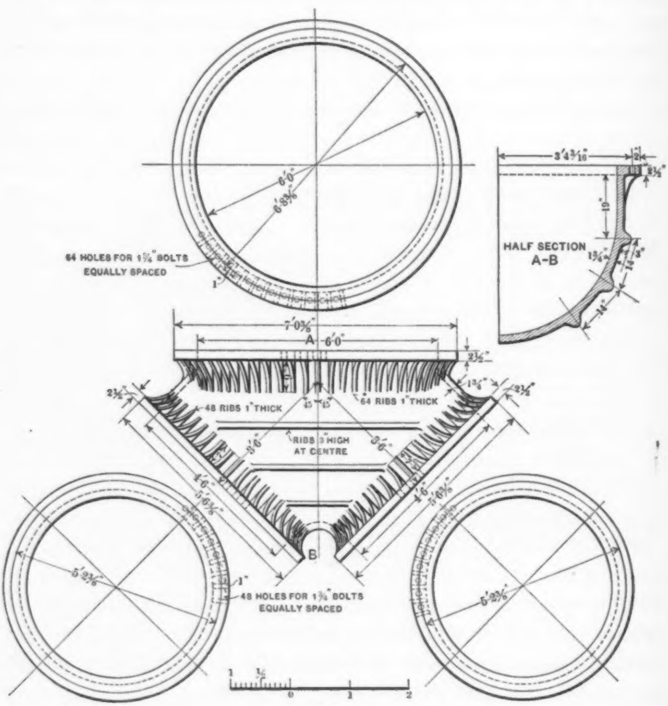

FIG. 10.

flange of the valve. Corrugated copper gaskets and red lead are used to make this connection water tight. The location of these valves and of the Venturi meters is shown in Fig. 9.

Venturi Meters.—The flow of water is to be measured continuously by two Venturi meters, one in each of the branch pipes supplying the receivers. They are built of cast iron for a pressure of 250 lbs.

per square inch, the sections being connected by flanges and bolts. The registers are of the latest type made, in which weights are used for operating the mechanism. They are placed inside of the power house and are connected with the meters by ¾-in. seamless brass tubing. The registers will record the flow from a minimum of 15 cu. ft. per second to a maximum of 130 cu. ft. If the flow exceeds 130 cu. ft., it will pass the meter without injuring it, but the excess will not be recorded.

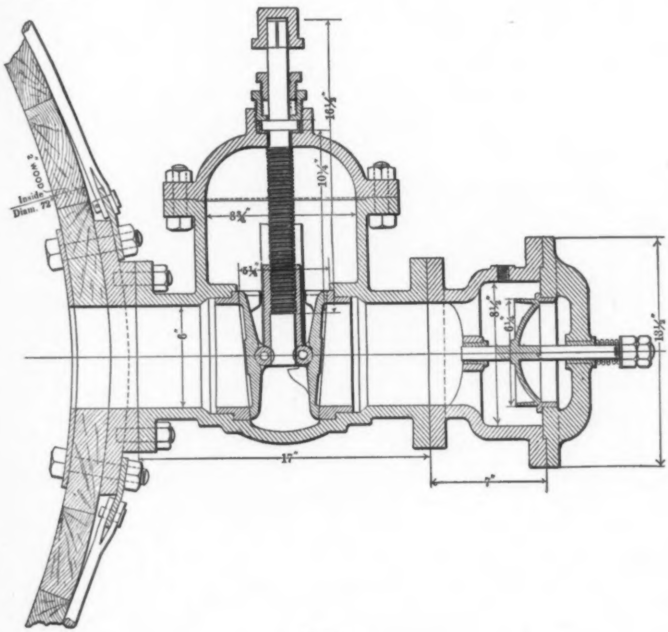

Fig. 11.

Breeches Pipe.—The connection between the 72-in. steel pipe and the two 54-in. branches is made by a steel casting, the general appearance of which is shown in Fig. 10. The pressure at this point is nearly 200 lbs. per square inch. Connection with the steel pipes is made by cast-steel angle flanges and bolts. A heavy concrete block is built around the casting, to secure it against the heavy longitudinal pressure, and to relieve the flanges and the adjacent pipe sections from strain.

Outlet Shaft and Stand Pipe.—At Station 247, the pipe line is in tunnel and but little below the lower hydraulic grade line, and about 50 ft. below the surface of the ground. This point was selected for the location of an outlet shaft. It is 6 ft. in diameter, and was sunk from the top through the solid rock to connect with the tunnel. With a full reservoir the top of the shaft comes close to the upper hydraulic grade, if the virtual slope is assumed equal to 0.002. The pressure in the pipe below the shaft can never exceed that due to the head of water corresponding to the top of the shaft. This reduces the static head, on the lower part of the pipe line, about 50 ft. In case the lower valves near the power house are closed, this shaft will, of course, overflow until the inlet valves at the dam are closed. A further important

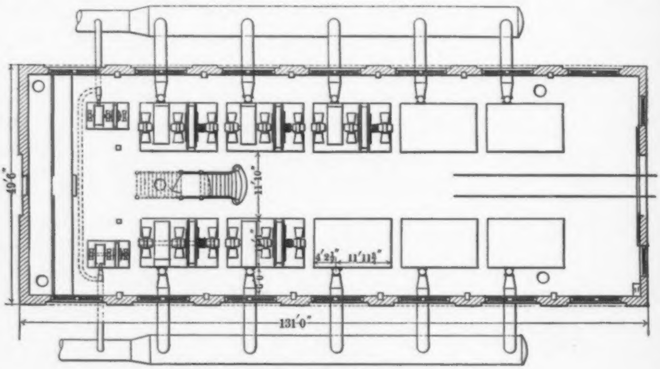

Fig. 12.

function of the shaft is to act as a relief outlet in case of accident to the lower part of the pipe line.

This shaft is not lined, but connects directly with the tunnel below. The wooden pipe in this tunnel is left out for a distance of about 100 ft., the pipes being connected to the tunnel by steel angle rings and flanges similar to those used for joining the steel and wooden pipes, and are bedded in concrete.

In addition to this shaft, a stand-pipe was built which connects with the 6-ft. steel conduit just below its junction with the wooden pipe, and a short distance above the heavy 72-in. valve. This stand-pipe is a wooden stave pipe, 49 ins. in internal diameter, built of twenty-four staves and banded in the same way as the 6-ft. pipe. It is laid on

a tangent and follows the contour of the ground up to the hydrostatic grade line. It is 550 ft. long, and is intended mainly to act as a safety valve in case the large valves below should be too suddenly closed, or in case of a collapse of the pipe.

These two relief openings will always permit the water to rise freely to the levels corresponding to the pressure at the points where they leave the main conduit. As the pipe is of practically constant diameter and of the same construction from the dam to the lower stand pipe, there will be an excellent chance for determining the true coefficient of friction in the wooden pipe for different velocities of flow.

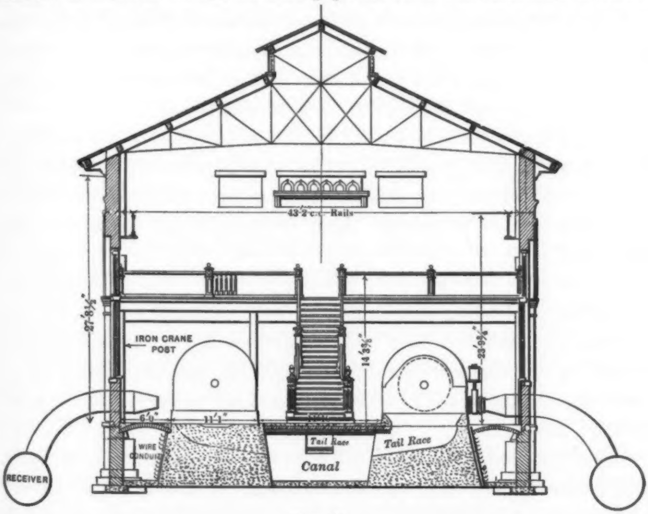

FIG. 13.

Air Valves.—These are of two kinds: single valves, 6 ins. in diameter, Fig. 11, and "group valves," consisting of ten 2-in. valves in each group, which are closed by rubber balls, giving an aggregate area equal to a single 6-in. opening; besides this, they have a 1½-in. blow-off valve.

During the process of filling the pipe with water all these valves remain open, allowing the air to escape, until the water pressure closes the valves one after the other. When the pipe is to be emptied, the reverse process takes place, the valves opening as the water flows out, thus permitting the air to enter as fast as the water escapes. A 6-in. gate valve was placed between the air valves and the main pipe. This

gate is intended to be left open under normal conditions, being closed only in case of damage to the air valve. These air valves are placed at all summits on the wooden and steel pipes.

Blow-Off or Mud Valves.—These are placed at all depressions in the pipe, both for emptying the pipe and also for removing accumulations of sand, earth and other foreign matters. They consist of 6-in. angle gate valves, through which the water is discharged into small timber flumes laid in covered trenches, and leading to the river.

To guard against injury from the sudden closing of valves, etc., a number of relief or safety valves are used close to the power house, which allow water to escape when the pressure exceeds 200 lbs. per square inch. Five of these valves are placed on the 6-ft. pipe just above the breeches pipe, five on each of the receivers, and one on each intake pipe between the receivers and wheels.

The large valves are enclosed in gate-houses of masonry and frame construction, large enough to protect them from the weather and allow of their operation. The smaller valves and the manholes are covered by timber boxes to protect them from frost and accidental disturbance.

HYDRAULIC AND ELECTRIC MACHINERY.

For the following description of the hydraulic and electric machinery, the author is indebted to Mr. L. S. Boggs, the electrical engineer of the Pioneer Electric Power Company, in charge of its erection. A plan and transverse section of the power house are shown in Figs. 12 and 13.

The installation comprises the following apparatus: Five 750-K. W. polyphase 2 300-volt generators; two 100-K. W. direct-current 500-volt exciters; five 1 200-H.-P. Knight water-wheels; two 135-H.-P. Knight water-wheels; one 7-panel generator switchboard; one 12-panel distributing switchboard; nine 250-K. W. step-up transformers; two blowers or cooling outfits; one 15-ton traveling crane; two Venturi water meters.

Receivers.—As noted in the general description of the works, the water is delivered from the pipe conduit into two receivers, which are buried in the ground, one at either side of the power house. They are 6 ft. in diameter, and, in their general appearance and the material used, closely resemble the regular steel pipe conduit. It may be noted, however, that the thickness of the metal is increased to $\frac{7}{8}$ in. in

order to allow for water-hammer. Besides this, the edges of all plates and straps were planed, and the rivet-holes reamed out fully $\frac{1}{8}$ in. after punching.

The receivers are provided with five safety valves each, which discharge when the pressure exceeds 200 lbs. per square inch, and an outlet gate at the bottom. From each of these receivers, five 30-in. and one 10-in. intake pipes extend to the walls of the power house to connect with the water-wheel nozzle pipes. Between these intakes and the nozzle pipes are placed the following valves, in order named; One 18-in. geared gate valve, one 18-in. hydraulic gate valve, and one 18-in. butterfly valve.

The 18-in. geared gate valve is only to be used in case of repairs to the particular machine that it governs, and is left open on all other occasions. The 18-in. hydraulic gate valve is piped up to a small D valve, which is placed back of the switchboard and under the floor, and by means of a lever on the switchboard, connected to this D valve, the gate can be opened or closed at the operator's will. This valve is the one which is to be used for starting or stopping a wheel. The 18-in. butterfly valve is operated by means of a worm gear from the governor, and is used in checking the speed of the wheel by reducing the head or pressure near the nozzle, and thus avoiding a sudden fall of head in the main pipe line, which would be detrimental to the proper working of the plant.

The nozzle for the water-wheels has six rectangular openings or ports $1\frac{11}{16}$ x $3\frac{1}{2}$ ins. in area. This nozzle is bolted to a tapering cast-iron pipe, securely fastened to the base of the machine, and the ports in the nozzle are made continuous, with a separation between each of them $\frac{1}{2}$ in. thick. Sliding back of the ports in this nozzle is a tongue, connected to the piston rods of two hydraulic cylinders which are placed one on each side of the head of the nozzle. These hydraulic cylinders are piped to another D valve, under the floor, back of the switchboard, which is also controlled by a lever on the switchboard. The operator is thus enabled to close one or more of the nozzle ports as he may desire. On the opposite side of the water-wheel from these hydraulic cylinders is a hand-wheel, which is geared to a rack that moves a similar tongue for opening or closing the nozzle ports on its extreme end. The levers that operate the hydraulic gate and nozzle are placed near the top of the switchboard. The set of levers for each water-wheel is placed in the panel governing the generator which is driven by the

wheel in question, so that the operations required in starting or stopping these machines are reduced to a minimum.

There is also between these levers an indicator with two hands, one showing the movement of the hydraulic gate and the other that of the nozzle.

Water-Wheels.—The water-wheels are 58 ins. in diameter, and have 45 bronze buckets cast in one solid piece; 14 of these will, when the nozzle ports are all open, receive the water at the same instant. The centers of the wheels are made of cast steel, the buckets being pressed on these steel centers, and secured with turned bolts, fitted in reamed holes, passing through both pieces of metal. These wheels were bored to fit, and are keyed to the generator shaft, each wheel being faced and perfectly balanced.

Each water-wheel is provided with two fly-wheels, about 70 ins. in diameter, each of which weighs about 2 tons, and is placed inside of a housing on each side of the wheel. These fly-wheels are banded with $\frac{3}{4}$ x 5-in. Ulster iron, shrunk on hot. They are split in three parts and are filled with metal, banded, bored to fit, and keyed to the generator shaft. They are turned on the face and nicely balanced.

The armature, armature shaft, two fly-wheels and one water-wheel, which comprise the moving parts, weigh as much as 15 tons, which greatly helps in maintaining a uniform speed, notwithstanding changes of head in the main pipe, or changes in the generator load.

The water-wheel, fly-wheels, nozzle and the two hydraulic cylinders are encased in a steel housing, bolted to the machine bed-frame. On the top of this housing is placed the speed-regulating apparatus or governor, which is driven from the water-wheel end of the armature shaft and is geared to the shaft of the worm gear which operates the butterfly valve already referred to. There is also a hand lever on the shaft of this butterfly valve that is used in regulating the opening until the governor picks up, as in the starting of a machine.

Between the two lines of machines and down through the center of the building underneath the concrete floor is the spillway into which the wheels discharge the water, and through which the water is carried back to the river from which it was taken.

On each side of the plant, near the generator switchboard and facing each other, are the registers for the two Venturi water meters elsewhere described.

Generators.—The generators used in this plant are of the General Electric type, with 24 poles, and, at 300 revolutions per minute, have an output of 750 K.-W. at 2 300 volts, and a frequency of 60 cycles per second, and the factory tests show that the variation in volts will be less than 5% with a constant speed, should the full non-inductive load be thrown off or on.

The bed plates of the generators were filled with cement after they were leveled up and securely anchored to their respective foundations. Between the machine foundations and the building foundation wall, on each side of the building, is a subway which runs the entire length of the building and across the rear, and in this subway are carried all the necessary piping for water-wheel controllers and all the wires between the generators and the switchboards. The cable connecting each generator to its respective panel on the generator switchboard is a three-wire concentric 250 000 C. M. lead-covered cable, and the exciting wires are a two-wire concentric No. 4 B. & S. lead-covered cable. In fact, all the machine connections to the switchboard are leadcovered cables.

Exciters.—The exciters used in this plant are six-pole 500-volt machines, and will give 100 K.-W. at 550 revolutions per minute. Each of these machines is ample for the entire exciting current that will be needed for the ten 750-K.-W. alternators, and they are each direct connected to a 135-H.-P. Knight water-wheel similar in every way to the 1 200-H.-P. water-wheels previously described. These exciter water-wheels are cross-connected to each receiver, so that either exciter can be operated from either receiver. The advantage of this is self explanatory.

Switchboards.—The generator switchboard consists of seven marble panels; five of these are for the alternators, one for the exciter, and one the instrument panel.

Each generator panel has the following apparatus on it: One 150-volt Thomson alternating voltmeter; one 1 000 K.-W. Thomson alternating wattmeter; one 25-ampere Weston ammeter; three S. P. Quick Break, D. T., 2 300-volt, 200-ampere switches; three S. P., 2 300-volt, 200-ampere fuse boards; two S. P., Q. B., D. T., 600-volt, 30-ampere switches; one field rheostat; two pilot lamps; one station transformer; three current transformers; two sets three-phase bus-bars.

The exciter panel is equipped with the following apparatus: Two 600-volt Weston voltmeters; two 300 ampere Weston ammeters; two

pilot lamps ; two S. P., Q. B., D. T., 600-volt, 200-ampere switches ; four S. P., 600-volt, 200-ampere magnetic cut-outs ; two field switches ; two Carpenter enamel field rheostats.

The instrument panel has the following apparatus: Two pilot lamps; two 5 000-K.-W. Thomson alternating wattmeters ; two 130-volt Bristol recording volt meters ; one Bristol recording water-pressure gauge; one synchronizer with two plug boards ; one ground detector with two plug boards ; two station transformers ; eight current transformers.

These panels are 36 x 90 x 2 ins. each. They are built of blue Vermont marble, with nickel fittings. There are two sets of three-phase bus-bars on the back, extending the entire length of the seven panels, as well as two bus-bars, also running their entire length, from which the exciting current is taken.

The speed-indicating apparatus consists of a tachometer coupled to the shaft of a small synchronous motor; there are two of these.

From the generator switchboard the current is carried to the distributing board by means of copper bars, of which there are two sets of three, connecting the two sets of bus-bars on the generator board with the two sets of bus-bars on the primary panels of the distributing board.

The distributing switchboard is in a gallery in the rear of the building and over the generator switchboard. Back of this distributing switchboard are the nine 250-K.-W. step-up transformers, the lightning arresters, and the two blowers for cooling the transformers.

The distributing board is divided into two sections, one the primary section, and the other the secondary section. Each section has six panels. In the primary section, four of the panels are for the low side of the step-up transformers, the remaining two being for the local distributing lines in the vicinity of the power plant. In the secondary section, four of the panels are for the high side of the step-up transformers, and two for the long-distance transmission lines.

The 2 300-volt primary panels are each equipped with the following apparatus: Three 350-ampere Thomson alternating ammeters ; one Thomson recording wattmeter; three S. P., Q. B., D. T., 2 300-volt, 200-ampere switches; three S. P., 2 300-volt, 200-ampere fuse boards; three station transformers; two current transformers; two sets three-phase bus-bars.

The 16 100-volt secondary panels have on them three S. P., Q. B., D. T. switches; three plug tube cutouts and two sets of three-phase bus-bars. The length of this distributing switchboard is 39 ft., and it is built of blue Vermont marble.

Back of the distributing switchboard and on a raised platform are placed the step-up transformers. These transformers raise the potential of the current from 2 300 to 16 100 volts, at which pressure it goes into the long-distance transmission lines. The transformers are connected up in sets of three, and the delta connection is used on both sides. At each end of the building in the gallery are placed the two blowers, direct connected to a $2\frac{1}{2}$-H. P. 500-volt direct-current motor. These blowers are used in cooling the step-up transformers, and force the air up through the bottom of the transformers, around the coils, and out at the top, thus giving good ventilation.

Transmission Line.—The transmission line is calculated to deliver about 3 000 H.-P. at the sub-station in Salt Lake City, distant about 38 miles, and consists of two circuits, making six wires of No. 1, B. & S. gauge.

The poles used on this line are of Oregon cedar, and are good, clear, straight poles, 30, 40, 50 and 70 ft. long, with 9-in. and 10-in. tops. There are two cross-arms on each pole for the wire; two wires are on the top arm 4 ft. apart, and four wires on the bottom arm each 2 ft. apart, a circuit being on each side of the pole; and these wires are so arranged that should a plane be placed perpendicular across the circuit it would show an equilateral triangle, with a wire at each angle, the length of the sides being 2 ft. These wires are transposed about every half mile. By this arrangement of the pole line wire, the inductive effect is reduced to a minimum.

About 6 ft. below the second cross-arm on the pole is a two-pin cross-arm, on which the telephone wires are strung, being transposed about every four poles, there being an average of about 50 poles per mile.

The current is fed into the transmission line at the power plant at 16 100 volts, and delivered to the step-down transformers at 13 800 volts. This will give an energy loss of about 10% in the line, and a potential loss of about 14 per cent. The substation step-down transformers deliver this current to the local distributing lines again at 2 300 volts. There are at present nine 250-K.-W. step-down transformers at

the substation, connected in a way similar to the step-up transformers, and the switchboard in the substation is similar in every respect to the distributing board in the power plant gallery. The cooling apparatus here is also identical with that used in the power plant, except that the motors used here are 60-cycle induction motors.

While the transmission lines are at present capable of delivering 3 000 H.-P. at the substation, with a 10% energy loss, if it should become necessary, the step-up transformers can deliver more than this by changing three wires on their high side, and delivering the current into the transmission lines at 27 000 volts. Thus the line capacity would be more than doubled.

The present installation of the power plant is only capable of delivering 3 750 K.-W. to its lines, but ample provision has been made to increase this amount to 7 500 K.-W. by installing five more 750 K.-W. machines, as new industries or manufactures spring up as the result of the advantages offered to them in Ogden and Salt Lake City.

There is one important feature in the arrangement of the machinery which should be noticed, viz., the complete duplication of all parts. All portions of the plant below the breeches pipe casting, at the lower end of the 6-ft. conduit, are absolutely symmetrical about the center line of the power house, each side being entirely independent of the other. This applies not only to the pipe and the receivers, but to all parts of the switchboards, etc., as well as to generators and water-wheels. Either one of the exciters, also, is capable of providing sufficient current for all the large generators, and can be run with water from either receiver. The advantage of this arrangement is that an accident to either receiver, or to one or more wheels or generators, would not result in the shutting down of the entire plant, but at the worst of only one side. For a short period all the required power could probably be supplied from one side of the power house.

Machine Shop.—The machine shop is a one-story brick building, covered with a standing seam steel roofing. The central part of the building is occupied by a well-equipped machine shop, while two wings serve respectively as a store-room and a superintendent's office.

The Dam.

The general location of the dam was determined by the topography of the upper valley, but it required considerable study to fix its exact

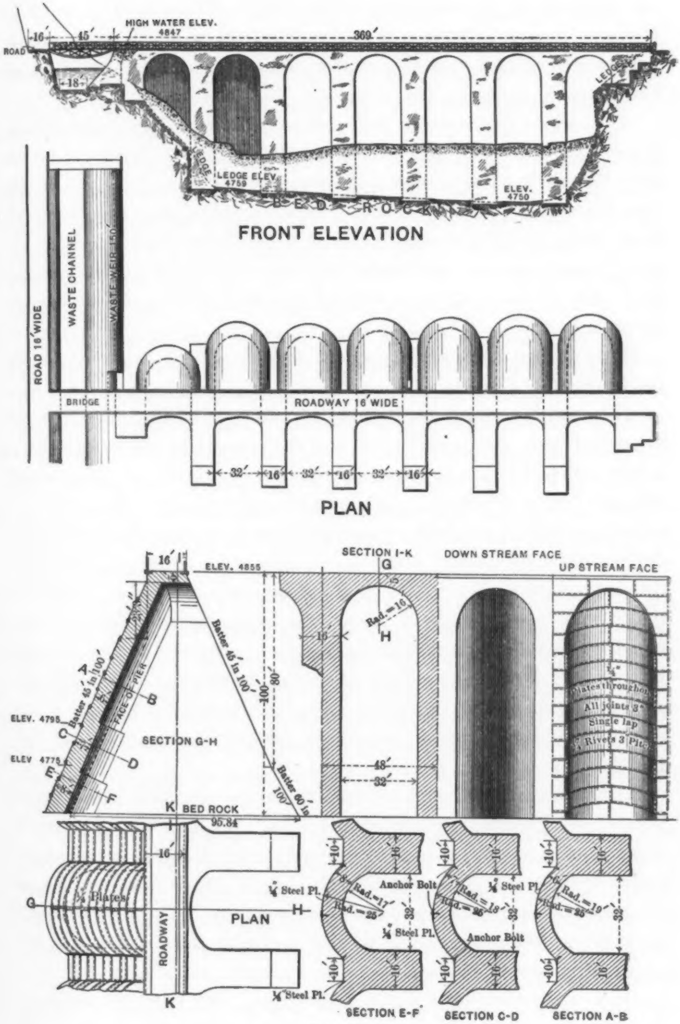
HIGH WATER ELEV. 4847
ROAD
16′
45′
369′
18′
LEDGE
LEDGE ELEV. 4759
ELEV. 4750
BED ROCK
FRONT ELEVATION
ROAD 16′ WIDE
WASTE CHANNEL
WASTE WEIR 150′
BRIDGE
ROADWAY 16′ WIDE
32′
16′
PLAN
16′
ELEV. 4855
SECTION I-K
DOWN STREAM FACE
UP STREAM FACE
Batter 45′ in 100′
FACE OF PIER
Batter 45′ in 100′
Batter 60′ in 100′
ELEV. 4795
ELEV 4775
SECTION G-H
Rad.=16′
48′
32′
100′
80′
All joints 3″
Single lap
K
BED ROCK
95.84
ROADWAY
PLAN
G
H
¼″ Steel Pl.
Anchor Bolt
Rad.=17′
Rad.=25′
Rad.=18′
Rad.=19′
SECTION E-F
SECTION C-D
SECTION A-B

Fig. 14.

site. A number of borings were made to the bed-rock, and the latter was explored with a diamond drill to a depth of from 3 to 15 ft. The location chosen combines the advantages of a short dam with a comparatively high position of the bed-rock. The cross-section is shown on the general plans of the dam, Fig. 14.

The bed-rock underlying the bottom is of fairly compact limestone, covered by 35 to 45 ft. of loose water-bearing gravel. On the sides of the cañon there are outcrops of the same formation. The crest of the dam is about 400 ft. long and its elevation above the ground about 60 ft., making a total height of fully 100 ft. above the bed-rock. An inexpensive form of waste water-way is provided by excavating the solid rock of the north bank, so that the dam itself is not used as an overflow weir.

The inlet tower for supplying the conduit will be placed close to the south end of the dam.

Although the location is entirely favorable to the construction of a masonry dam of the usual form, and the cost would not be excessive, it was determined to inquire into the feasibility of adopting some different design by which a saving might be expected. The idea was entirely excluded, however, of doing so at the expense of either safety or durability, by making a lower assumption as to the forces to be resisted, or the necessary factors of safety. It was believed, however, that it would be possible to reduce the amount of masonry required by adopting a design in which the stresses coming on every part would be more uniform and definite than in massive dams, so that the strength of the material would be more fully utilized. Following out this line of investigation, a number of different designs were studied in detail.

The plan finally adopted provides for a concrete dam consisting of isolated piers united by segmental arches. Both in the quantity of material used and the cost of construction it promises to be considerably cheaper than a dam of the usual type. It is believed, too, to meet all necessary requirements as to strength, water-tightness and durability. The statement as to the saving in cost is based on the result of an actual bidding made by a number of experienced contractors on detailed plans and specifications. While the bids differed largely as to the actual amounts, they were, in every case, considerably lower than the tenders for a masonry dam which were made at the same time.

In addition to this design, the question was studied of substituting a steel structure for the upper 60 ft. of dam. Although, under the conditions prevailing in Ogden Cañon, a steel dam proved to be uneconomical, there may be places where the result would be different. For this reason some forms of steel dams, given in Appendix B, may be of some interest.

Concrete Dam.—The dam consists of concrete masonry, but a thin steel plate covering is bolted to the up-stream face to prevent abrasion and the percolation of water. As shown in Fig. 14 there are to be six separate piers and two abutments, which are joined together, both on the up-stream face, and on top of the piers, by circular concrete arches. The piers are 16 ft. thick, while the arches have a clear span of 32 ft. The extrados of the arches is cylindrical, with a radius of 25 ft. The thickness of the arch rings varies, being 6 ft. for the upper 60 ft. of dam, 7 ft. for the next 25 ft., and 8 ft. below this point.

The arches at the top, which will carry a roadway 16 ft. wide, are semi-circular, the intrados having a radius of 16 ft. They are practically continuous with the arches of the up-stream face. The spandrel spaces above these arches will also be filled with concrete, and a stone coping will be laid on top, on either side. On top of this coping there will be an iron hand-railing or an ornamental stone parapet.

The steel facing will be ¼ in. thick. The plates in front of the arches will be 22 ft. long, while the flat plates on the piers will be 10½ ft. in length, making lap-joints with the curved plates on the arches. There will be lap-splices, with a single row of ¾-in. rivets, spaced 3 ins. apart. The joints will be made water-tight by caulking. The surfaces coming in contact with the concrete will be cleaned, but not painted, while the outer surfaces will be painted with an asphaltum paint.

Stresses and Cross-Sections.—The dam is designed purely as a gravity structure, and the way in which the forces act will be readily seen by an examination of the plans. The arch-rings act simply to transfer the water-pressure to the adjacent piers, which must be of sufficient size and strength to withstand the entire hydrostatic pressure that comes on both piers and arches. As customary, the water is assumed to extend from the top of the dam to bed rock, but is not supposed to penetrate beneath the piers and exert an upward pressure.

The arches are circular segments, so that their central lines coin-

cide exactly with the line of pressure for water pressures acting normally to the extrados. Hence the compressive strains are uniform in the arch-ring at any given elevation and are readily found by the formula $T = pR$, in which T is the compressive strain in an arch-ring 1 ft. in height, p is the water-pressure in pounds per square foot, and R is the radius of the center line in feet. The actual stresses, as thus computed, are quite moderate, being 96 lbs. per square inch for the 6-ft. arch, 106 lbs. per square inch for the 7-ft. arch, and 120 lbs. per square inch for the 8-ft. arch. The minimum thickness of 6 ft. is arbitrarily fixed from practical considerations.

The determination of the best and most economical cross-section for the piers is a somewhat tedious, tentative process. The requirements as to strength and stability are the same as for a continuous masonry dam, but the water pressure to be withstood by each foot of pier is much greater, so that a heavier section is needed. Each pier acts as an abutment for two arches, but, owing to the symmetry of the construction, the components of the thrust parallel to the face will always balance. Hence, the resulting force tending to overturn the pier acts at right angles to its face, and is equivalent to a pressure on a plane, the width of which is equal to that of the pier and of two half arches. As the piers are 16 ft. wide and the arch-span is 32 ft., the pressure of the water on the pier is equal to that which would be exerted by a fluid with a specific gravity of 3, *i. e.*, weighing 3 x 62.5 or 187.5 lbs. per cubic foot. The weight of the masonry is taken at 145 lbs. per cubic foot.

The usual standards for strength and stability were followed, and the graphic analysis of the adopted cross-section is shown in Fig. 15. All forces are given in cubic feet of masonry.

As there shown, the factors of safety are the following:

As to Overturning.—The moment of the forces which resist overturning, when taken about the down-stream edge of the dam, at any elevation, are more than twice as great as the moment of overturning at the same point.

As to Sliding.—The angle between the resultant on any joint and the normal to the joint nowhere exceeds $\tan.^{-1}$ 0.85 or 40° 22′. Hence, a coefficient of friction of 0.85 in the masonry will be sufficient to prevent sliding. This is considered amply safe in the case of a concrete dam in which there will be no joints, properly speaking, but, on the contrary,

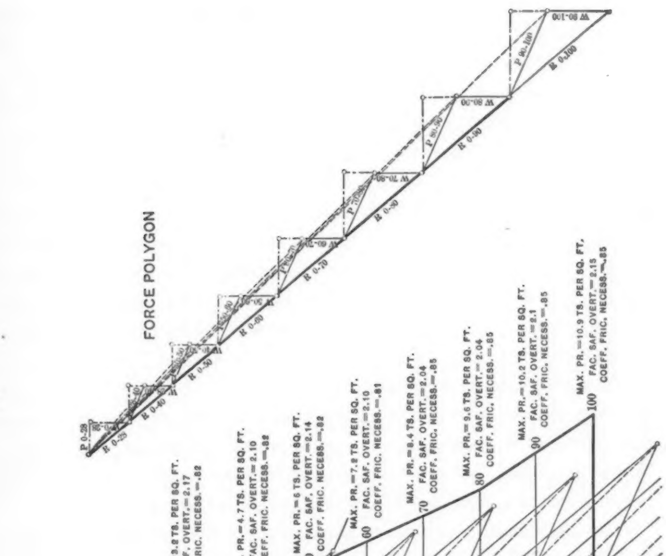

FIG. 15.

considerable cohesive strength. It is true that in standard sections for masonry dams the angle between the resultant and the normal is usually somewhat smaller than the above value. In such dams, however, the dimensions of the cross-section are not increased by this requirement, as the length of the joints is mainly fixed by the necessity of keeping the resultant within the middle third.

As to Internal Stresses in the Masonry.—The resultant at all joints is kept within the middle third, so that there are no tensile stresses. The compressive strains for a full reservoir nowhere exceed 10.7 tons per square foot, this being the stress at the bottom, and are less at other points. While this value is somewhat greater than is usual in dams 100 ft. high, it leaves a large factor of safety, and has been exceeded in actual constructions, some of which have stood for several centuries. It must be borne in mind here, too, that in standard dam sections the lengths of joints up to a height of 100 ft. are not determined by the limiting compressive strains, but by the necessity of avoiding tensile stresses and of maintaining a proper stability against overturning. Where the water face is vertical, both of these requirements are met by keeping the resultant at all joints within the middle third.

The section adopted under these conditions is approximately trapezoidal, and differs from the standard section by having a heavy batter on the up-stream face. This batter is essential. The length of the joints in the upper part of the dam (as far as elevation 80) were determined by the requirement as to the middle third, but below that elevation it was necessary to extend the base so as to keep the stresses on the masonry within moderate limits.

Specifications for Material.—Both piers and arches are to be built of concrete, mixed by machinery and carefully rammed into well-braced molds, so as to form a homogeneous, monolithic structure. The steel-facing will serve as the upper side of the molds. Portland cement will be exclusively used, the proportions being one part of cement, two of sand, and four of broken stone, for the arches, for the exterior 2 feet of the piers and for all concrete deposited under water. For the rest of the work, the proportions will be one, three and five. In computing the amount of cement used, it shall be measured as packed in barrels, the cubic contents of a barrel of Portland cement weighing 400 lbs., being taken as equal to $\frac{1}{8}$ cu. yd. The cement will be carefully tested before acceptance as to strength and fineness. The broken

stone shall be clean, durable limestone, while the sand must be clean, coarse and silicious. The steel used for plates and rivets shall conform to the specifications given in Appendix A.

Method of Construction.—The method of sinking foundations will depend on the nature of the material and the amount of water encountered in the pits. It is expected that the excavation of separate trenches for the piers will greatly reduce the difficulty of handling the groundwater. The earth excavation will be carried down with sloping sides until water is reached. Below this level the trenches will be timbered and braced. The piers and arches will be sunk into the bed-rock 2 or 3 ft.

Quantities.—The amount of material for the above arch dam, as well as for a dam of the ordinary form, is given below:

	Ordinary dam.	Arched dam.
Concrete Masonry.—		
In dam proper	37 200 cu. yds.	26 000 cu. yds.
In overflow weir	1 700 " "	1 700 " "
Total concrete	38 900 cu. yds.	27 700 cu. yds.
Excavation.—		
Earth excavation	33 700 cu. yds.	27 550 cu. yds.
Rock excavation	2 400 " "	2 400 " "
Steel-plate facing		350 000 lbs.

The unit prices bid by the several contractors for the different classes of work were almost identical for both forms of dam, so that the total cost of the new form was from 12% to 15% less than that of the old type. By omitting the steel plate facing and substituting an asphalt coating, which appears to the author quite feasible, a still greater saving would be effected.

The work was carried out under the direction of C. K. Bannister, M. Am. Soc. C. E., as chief engineer, while Messrs. Willard Young and H. M. McCartney successively held the position of assistant chief engineer. Mr. R. F. Hayward was consulting engineer for the hydraulic and electric equipment, while George H. Pegram, M. Am. Soc. C. E., acted in an advisory capacity as consulting engineer. The location and early construction were in charge of Mr. F. N. Snyder, who was succeeded by Mr. S. E. Reaugh. To the author were entrusted the designing of the details of the pipe conduit, and the studies for the dam, as well as the mathematical work connected with the plant, excepting the electrical and hydraulic machinery and transmissions. Mr. J. E. Rhodes was in charge of the work on the pipe conduit for the contractors, Messrs. Rhodes Brothers.

APPENDIX A.

EXTRACTS FROM STEEL PIPE SPECIFICATIONS.

"*Requirements for Steel Plates.*—The steel shall be of the class termed 'soft medium,' and shall be made by the open-hearth process, either the basic process or the acid process, as the engineer may determine. If made by the basic process, the percentage of phosphorus shall not exceed 0.04 and of sulphur shall not be greater than 0.04; if made by the acid process, it shall not contain more than 0.07% of phosphorus and not more than 0.04% of sulphur. The percentage of manganese shall not be greater than 0.60 per cent. Each sheet shall be uniformly homogeneous in quality, and should a reasonable doubt exist as to the quality or uniformity of the steel furnished, the engineer may order additional tests before acceptance.

"Test pieces shall be furnished from at least 20% of the finished material of each melt, but at least two test pieces shall be made from every melt. The plates or sheets from which test pieces are taken shall be selected at random by the inspector, and each piece shall be numbered with the corresponding melt number.

"Tensile test pieces shall be at least 16 ins. long, and shall have for a length of 8 ins. a uniform planed-edge sectional area of at least ½ sq. in., the width in no case to be less than the thickness of the piece.

"Bending test pieces to be 12 ins. long, and to have a width not less than four times the thickness, with edges planed smooth.

"Punching test pieces shall be 1¾ ins. wide and not less than 10 ins. long.

"Drifting test pieces shall be 3 ins. wide and not less than 5 ins. long.

"Test pieces as above shall give results as follows:

"Ultimate strength, 55 000 lbs. to 65 000 lbs.

"Elastic limit, not less than one-half ultimate strength.

"Elongation, not less than 24% in 8 ins.

"Reduction of area at fracture, at least 48 per cent."

"All fractures shall be fine, silky and free from crystalline appearance, or from indications of injurious treatment or insufficient working.

"Bending test pieces shall bend double under the hammer, cold, without signs of cracking.

"In punching test pieces, a row of eight holes, ¾ in. in diameter and 1¼ ins. between centers, shall be punched without any cracks.

"In drifting test pieces, not less than two holes, ¾ in. in diameter, spaced 2 ins. between centers, shall be punched and then enlarged by

blows from a sledge hammer upon a drifting pin until said holes are $1\frac{1}{4}$ ins. in diameter, without showing signs of failure or cracking on the inside of the hole or edge of the plate. Punching and drifting tests to be made cold.

"The plates must also admit of cold hammering or scarfing to a fine edge at the laps without cracking, and the test pieces must furthermore withstand such quenching, forging and other tests as may satisfy the inspector as to the temper, soundness and fitness for use of the material.

"Any failure of test pieces, taken at random as aforesaid, to conform to the above requirements may, at the discretion of the engineer or inspector, cause the rejection of the entire product of the heat or melt from which such pieces are taken.

"All finished material shall be free from laminations, cracks, blisters, scale or cinder spots, and have clean edges and good surfaces free from bends. The plates shall be fully up to the required thickness at the edges. Any plate whose thickness at any point may be found less than the required thickness by more than one one-hundredth of an inch shall be rejected without appeal. Furthermore, at least 95% of the plates must be of the full required thickness at all points.

"Plates varying more than 5% from the standard weights per square foot will be rejected, and no allowance will be made for weights more than 5% in excess of the standard weights required.

"The plates shall be rolled as flat as good mill practice will permit, and each plate shall be cut to the dimensions required. A variation of more than $\frac{1}{4}$ in. from the dimensions required on either length or width of plate will not be permitted, and in no case shall they be scant of the required dimensions. All material shall be finished in a first-class, workmanlike manner.

"The Engineer of the Power Company, or his representative, shall have the right at all times to inspect the process of manufacture and testing of any and all plates, and may have, in his discretion, an additional number of test pieces, not more than one-fourth of the whole, prepared as above from such melts as he may designate, for testing under his own supervision, at the expense of the Power Company.

"*Requirements for Steel Rivets.*—Rivets shall be made of a good grade of soft steel, and shall have a tensile strength between the limits of 56 000 lbs. and 64 000 lbs. per square inch, with an elastic limit of not less than 36 000 lbs., and shearing strength not less than 72% of the ultimate strength. Physical tests shall be made by the Inspector to determine the elongation and area at point of fracture. In an ordinary test piece, as described above, the elongation shall be not less than 24%, and the reduction of area at point of fracture not less than 48 per cent. The material shall also be of such quality as will stand bending double and flat, before and after heating to a light yellow heat

and quenching in cold water, without sign of fracture on the convex surface of the bend. All rivet material not conforming to the above requirements shall be rejected.

"It is understood and agreed that any plate that shows any defect during the process of punching, bending, riveting and in manufacturing into pipes shall be rejected, notwithstanding that the same may previously have been satisfactorily tested.

"All plates and rivets must be free from rust and kept under cover from the time of manufacture of the plates and until the completed pipe is dipped or coated. At the factory, the plates must be loaded under cover upon suitably covered cars. They must be delivered under cover at the pipe shop and must be kept under roof and cover until ready for shipment, and in no way exposed to the weather or to moisture. In cases of accidental rusting, the rust must be removed from the plates before proceeding with the manufacture of the pipes.

"*Manufacture and Laying of the Pipe.*—All seams shall be butt seams, with straps exactly fitted to the curvature of the main plates.

"The round straps (uniting adjacent sections) shall be placed on the outside of the pipe only; they shall be 11 ins. wide and their thickness shall be the same as the thickness of the plates in the pipe. Each strap shall have four rows of rivets placed zigzag, and spaced as indicated on the detailed plans.

"The longitudinal seams shall be united by two butt straps, one on the inside and the other on the outside of the pipe. The outer strap shall be 11 ins. wide and the inner $16\frac{1}{2}$ ins.

"The longitudinal joints shall in all cases be placed at the top of the pipe, both in the straight portion and in the elbows, so that the straps shall be entirely continuous throughout the entire length of the pipe.

"The thickness of the longitudinal butt straps (both inside and outside) shall be $\frac{1}{2}$ in. for the portion of the pipe built of $\frac{11}{16}$-in. and $\frac{5}{8}$-in. plates, and $\frac{3}{8}$ in. for the rest of the pipe line.

"There shall be six rows of rivets at the longitudinal joints, of which four rows shall go through both butt straps and the main plate, and two rows through the wider or inside butt strap and the main plate only.

"The spacing shall be zigzag, with a double pitch in the row of rivets that goes through two thicknesses only.

"All butt straps, both longitudinal and circumferential, shall be 'rolled' to the correct circular curve necessary to fit the pipe closely.

"The edges of the outside straps, both round and longitudinal, shall be planed for caulking.

"The inside longitudinal butt straps shall be of the same length as

the main plates; they shall be as straight and true as possible, but shall not be caulked.

"The outside longitudinal straps, where they butt against the edges of the round straps, shall be planed down to a feather edge for a short distance and extended under the round straps, the edges of the latter being caulked.

"The splices in the round straps shall be scarfed joints, extending over three rivets.

"The under strap at the lap must be scarfed or thinned by machinery, without being heated; the upper strap is to remain of the original thickness for caulking.

"The diameters of the rivets used shall be as follows:

"For the portion of the pipe line built of—

$\frac{11}{16}$-in. and $\frac{5}{8}$-in. plates..........Diameter of rivet $1\frac{1}{8}$ ins.

of $\frac{9}{16}$-in. and $\frac{1}{2}$-in. plates..........Diameter of rivet 1 in.

of $\frac{7}{16}$-in. and $\frac{3}{8}$-in. plates..........Diameter of rivet $\frac{7}{8}$ in.

"These sizes shall be the diameters of the rivets when cold.

"The rivet holes shall be punched of $\frac{1}{16}$ in. greater diameter than that of the cold rivet, except in the case of the $1\frac{1}{8}$-in. rivets. In this latter case, the rivet holes shall be punched of $1\frac{1}{8}$-in. diameter on the die side and reamed to $1\frac{3}{16}$ ins.

"All riveting in the shop must be done by steam, compressed air or hydraulic machinery, capable of exerting slow pressure sufficient for the formation of perfect rivet heads, of such form and dimensions as may be directed by the engineer.

"All burrs, caused by punching, on the lower side of the plate, must be removed by countersinking; all burrs produced by shearing must be removed by filing or chipping.

"The sheets must be pressed closely together while the rivets are being driven and until the rivet heads are formed. The riveting will be inspected by the Engineer of the Power Company, and all rivets which do not properly fill the holes, or which may be found defective in any respect, must be cut out and replaced by and at the expense of the contractor.

"All riveted seams and joints of every description shall be thoroughly caulked on the outside of the pipe in the best and most workmanlike manner usual in first-class boiler work. The caulking of all seams made in the shop must be done before the coating is applied in the pipe, and every precaution must be taken, both in the shop work and field work, to insure the utmost strength and tightness."

APPENDIX B.

DESIGNS FOR A STRUCTURAL STEEL DAM.

Two types, Plans A and B, are shown in the plans, out of a number considered, which were studied in detail, so that the quantities of material may be relied upon as correct.

Plan A.—This form of dam consists of a number of cantilever trusses spaced 10 feet apart and braced together, and a steel plate

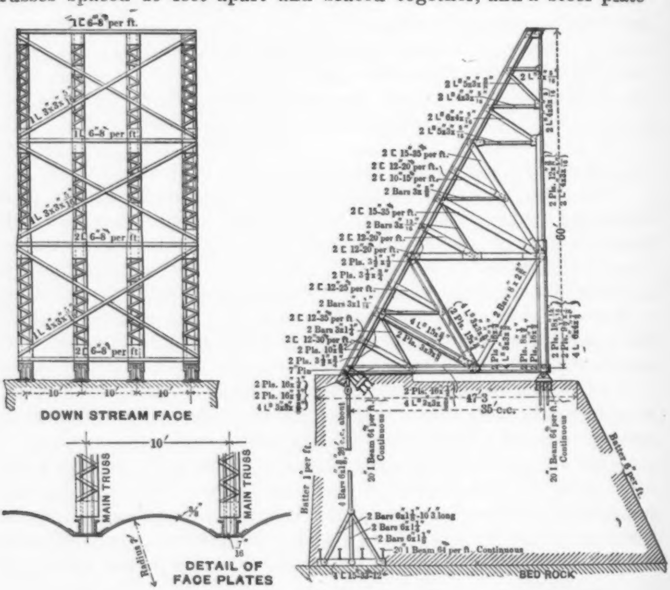

FIG. 16.

covering, which receives the direct water pressure and transmits it to the trusses. The latter are 60 ft. in length, with a base 35 ft. in width, this being nearly the same as the thickness of a standard masonry dam at the same elevation. The construction is shown in Fig. 16.

The outline of the trusses is triangular, the down-stream posts being vertical, while the water face has a heavy batter, as the vertical component of the water pressure on the up-stream face is essential to the stability of the dam. Theoretically, a curved face would lighten the steel work slightly, but not enough to outweigh the advantages of a straight chord.

The steel work rests on a concrete or rock foundation, to which it is securely anchored. This foundation need not be essentially different in size or shape from the equivalent portion of an all-masonry dam, so in comparing relative costs only the upper 60 ft. need be considered.

The trusses are designed according to ordinary bridge practice, with simple details, the connections in the upper portion being by rivets, and in the lower part by turned pins. They should be built according to the specifications for materials and workmanship used for the highest grade of railway bridgework.

The stresses in the different members were determined graphically, the only forces acting being the water pressure, the weight of the dam, and the resistance of the anchorage. All these forces are definite in magnitude and direction to a greater degree than in most other kinds of steel construction.

The tensile stresses were taken at 15 000 lbs. per square inch of net section, while for compression the following formula was used, viz.:

$S = 12\ 000 - 45\ \frac{L}{R}$ in which S is the permissible strain per square inch; L is the full length of compression member, and R is the radius of gyration of the cross-section.

Where beams are subject to cross-bending, the net tensile strains are 15 000 lbs. per square inch.

The trusses are braced together in sets of four by comparatively light bracing in the plane of the vertical posts. The long horizontal bottom struts are also connected by bracing. Every fourth panel is left without bracing, so that longitudinal expansion may take place without straining the metal anywhere, the convex plates in the water face allowing a slight motion. Expansion at right angles to the face is provided by short rocking links at the foot of the vertical posts.

Two forms of plate facing were proposed, the first consisting of buckle plates resting on rolled I-beams, while in the second a single curved sheet of steel, extending from one truss to the next, sustains the water pressure. The strength of the buckle plates and beams is computed by the usual methods, the thickness of the former varying according to the depth.

The concave sheets in the second design are circular segments with a radius of 7 ft. and a 10-ft. chord. All sheets are of the same size, and joined to adjoining sheets by caulked riveted joints.

These plates are uniformly $\frac{3}{8}$ in. in thickness. Their strength is readily calculable, as the water pressure is constant at any given elevation and the tensile strain is given by the formula: $T = pR$ as in the case of circular arches. For a depth of 60 ft., $p = 60 \times 62.5 =$ 3 750 lbs. per square foot, and $T = 3\ 750 \times 7 = 26\ 250$ lbs.; hence the gross tensile strain on $\frac{3}{8}$-in. plate will be only 5 830 lbs. per square inch.

The steel trusses are connected to the foundation by anchor bars on the up-stream end, while the vertical posts rest on steel bed-plates and shoes. The horizontal shear is transmitted by special inclined struts.

Plan B.—This design is based on F. H. Bainbridge's patent, dated April 16th, 1895. The structural frame is not a truss or cantilever, but consists simply of a series of struts which carry the thrust of the water direct to the foundation. These long struts are, of course, securely braced, so as to prevent buckling in any direction. The steel facing consists of buckle plates or concave sheets of steel as already described, which are fastened to an inclined chord to which the struts

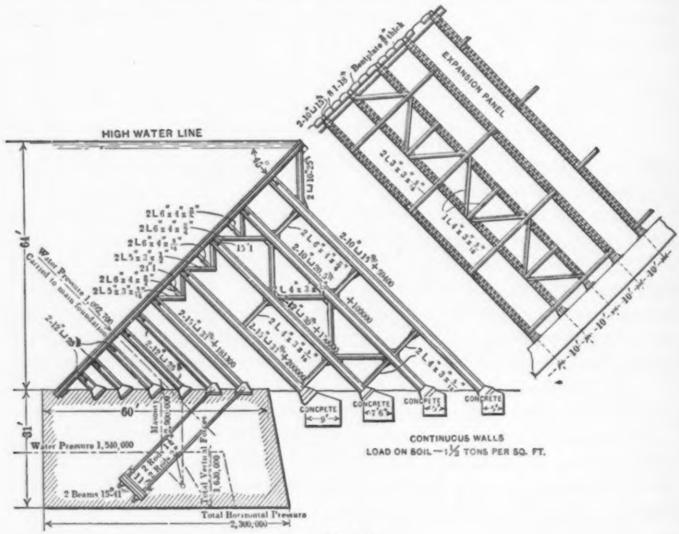

FIG. 17.

connect. The struts and the steel face are both placed at an angle of 45°, with the horizon, so that there is no uplifting effect on the foundation below. The amount of steel in this dam is less than in Plan A, though the saving will be in most cases more than offset by the increased cost of the foundation.

In Fig. 17, the struts are shown as supported on separate shallow foundations, but in most cases, it will be necessary to carry them down to bed-rock, which would increase the amount of masonry very much. On the other hand, where the bed of the stream consists of solid rock, or is overlaid by a small amount of earth, no special

foundation will be required. In such a location, this form of dam may prove economical, and might be adopted with advantage.

The relative amount of materials required to build steel dams, according to Plans A and B, is given in Table No. 2, as well as the amount of masonry contained in a standard masonry dam of the usual form. The comparison is limited to a dam 60 ft. in height, but the metal required for a proper anchorage of the steel dam is taken into account.

TABLE No. 2.—COMPARATIVE STATEMENT OF QUANTITIES IN STEEL AND MASONRY DAMS.

Height of dam, 60 ft.; length assumed, 1 ft.

Plan A.—Steel Cantilever Dam with Buckle Plate Facing.

Trusses and bracing	4 530 lbs.	
Shoes, bed-plates and anchorage	1 805 "	
I beams	1 180 "	
Buckle plates	1 285 "	
		8 800 lbs. per lineal foot.

Plan A.—Steel Cantilever Dam with Curved Plate Facing.

Trusses and bracing	4 745 lbs.	
Shoes, bed-plates and anchorage	1 805 "	
Curved face plates	1 500 "	
		8 050 lbs. per lineal foot.

Plan B.—Steel Strut Dam with Buckle Plate Facing.

Total steelwork.................................. 7 650 lbs. per lineal foot.

Plan B.—Steel Strut Dam with Curved Plate Facing.

Total steelwork.................................. 7 000 lbs. per lineal foot.

Standard Masonry Dam, 60 ft. high.

Total masonry = 48 cu. yds. per lineal foot of dam.

DISCUSSION.

Mr. Frizell. J. P. Frizell, M. Am. Soc. C. E.—This system of water power presents a problem in the regulation of water-wheels which is worthy of consideration. There is a conduit closed its whole length, and in checking the quantity of water which passes through a wheel it is necessary to check the momentum of a column of water some 6 miles long. Those who run the establishment will meet with difficulties in the regulation of the wheels which will not be met by fly-wheels. The total weight of the column of water will be thousands of tons, and in diminishing the power at the station by one-half, which has to be done often in electric work, it is necessary to destroy the momentum of, perhaps, 30 000 tons of water at a velocity corresponding to a height of 2 or 3 ins., amounting to a gross momentum of from 5 000 to 7 000 foot-tons, which would be very difficult to deal with. The safety of the pipe is not the serious question in this problem, but the manner of controlling that enormous momentum consistently with the requirements of an electric power plant running at a uniform speed.

Mr. Skinner. F. W. Skinner, M. Am. Soc. C. E.—The field work on the pipe line described in the paper was done under difficult conditions, which were met admirably from a structural point of view. The erecting outfit for the bridges, for example, was very light, and all field joints of the riveted structures were made with bolts instead of rivets. The connections were accurately fitted at the shop with reamed holes, and the whole bridge was put together with tapered bolts, which were replaced afterwards with carefully turned cylindrical bolts, resulting in a piece of work of such accuracy of adjustment that the author should make some statement concerning it in his closing correspondence.

It is of interest to compare this Utah riveted pipe line with one recently constructed in Paris to connect the Verneuil and Vigne water supplies with the distributing mains. It was 1.5 m. in diameter, 8 to 12 mm. thick, and shop riveted in 6-m. sections, each consisting of three courses and weighing about 3 000 kilos. At each end of the sections a hoop was riveted to form a narrow bead. The pipe line was constructed in a tunnel of small cross-section and supported on cast-iron shoes. The tunnel was so small, 2.4 m. wide, and the pipe so large, that a special track was built from the bottom of the entrance shaft to the heading, on which to run a sling truck. The axles of this truck were not straight, but consisted of arched riveted girders from which a section of pipe could be hung. The truck was pushed to the end of the completed pipe by an electric locomotive, except on the steep grades, where the locomotive was detached and the car lowered by means of a windlass. The field joints were not riveted, but were made by screwing a sleeve against rubber gaskets held by the beading before

mentioned. All power for driving the electric locomotive was furnished by a storage battery it carried. This was charged at night from a dynamo driven by an engine near the shaft where the pipes were lowered. The locomotive and car had horizontal guide wheels with rubber tires bearing against the tunnel walls, and an elaborate rotary centering machine was run inside the pipe to adjust the joints of the successive sections. Mr. Skinner.

CORRESPONDENCE.

R. F. HAYWARD, Esq.—In the design of the electrical equipment of the Pioneer Electric Power Company's plant the following problem presented itself, viz.: To supply energy for light, power, railways and electrolytic purposes in Ogden and the immediate vicinity of the power house; to supply energy for the same purposes in Salt Lake City, at a distance of 37 miles from the power house, and to supply power for smelting and mining purposes at points from 10 to 30 miles beyond Salt Lake City. Mr. Hayward.

Within the area covered there is a good market for power, and though the cost of slack coal is not more than $2.25 per short ton, the majority of steam plants are poorly designed, or operated under disadvantages which make the cost per horse-power per annum vary from $70 to $120 on 24-hour service. In order to supply the market with any success, absolute continuity of service and good regulation must be maintained, and every portion of the plant has been designed with this object in view.

The three-phase alternate-current system was chosen as being in every way suitable to the service required, both on account of its flexibility and economy of transmission. The fact that the smaller transmission plant of the Big Cottonwood Power Company at Salt Lake City was installed on this system and might eventually be used in conjunction with the plant of the Pioneer Electric Power Company was also a factor in the case.

A frequency of 60 cycles per second was chosen, as a very large part of the energy will be used for lighting purposes; and while a lower frequency is at the present time most suitable for direct-current work, it will be but a short time before rotary transformers can be built satisfactorily for 60 cycles.

The question of voltage is of course all important. The power house is located about two miles from the center of Ogden, where about 1 000 H.-P. will be used. It was therefore decided to wind the generators for 2 000 volts, in order to avoid the use of step-up transformers for the Ogden service. The voltage of the transmission line was placed at 15 000 volts, this being as high as it was deemed advis-

Mr. Hayward. able to go at present, but the transformers have all been tested to 40 000 volts and can be connected up to give 27 000 volts on the lines. This pressure will be tried carefully, and, if successful, used regularly. With the successful application of 27 000 volts, it will be commercially possible to transmit power to the mines at Mercur, more than 40 miles beyond Salt Lake.

The system is arranged throughout in duplicate. There are two circuits for the local distribution and two for the transmission lines, and the switchboards are so arranged that any generator and any set of transformers can be thrown at will on either one or the other of these circuits. Thus one circuit can be used for supplying energy for lighting, the other for street railways and power, where the regulation is not so important.

Every precaution has been taken against interruption in the transmission lines, and they will probably be duplicated ere long. The lines are thoroughly protected by lightning arresters.

By means of the Venturi water meters and the electrical measuring instruments, it will be possible to obtain continuous records of the quantity of water used; also, of the energy sent out from the power house, and the energy received at the sub-station. It will also be possible to take instantaneous records of the real and apparent power in any circuit, together with electrostatic measurements of the voltage on the high-tension lines. The system of measurements provided is as complete as can possibly be made for commercial purposes.

The machinery was manufactured under very stringent guarantees. The specifications called for a commercial efficiency of 95% in the generators, and on the test at the factory this figure was reached within a few tenths of 1 per cent. The efficiency of the transformers is also very satisfactory, being over 98 per cent. The efficiency of the transmission lines will be about 90% when delivering 3 000 H.-P. at Salt Lake City, with an initial pressure of 16 000 volts. With 27 000 volts, the capacity of the line will be about 6 000 H.-P. for the same efficiency.

Every care has been exercised to obtain efficient regulation. The water-wheels are each provided with two very heavy fly-wheels and are fitted with electrical relay governors. The generators on test showed that they would regulate within 5% at constant speed. The drop on lines and distributing mains has been kept as low as possible throughout the system. Speed indicators and recording voltmeters have been provided to check the regulation continuously.

Mr. Tratman. E. E. Russell Tratman, Assoc. M. Am. Soc. C. E.—In connection with the large steel pipe line of the Pioneer Company's plant, reference may be made to a story regarding the pipe line system of the Big Cottonwood Power Company, of Salt Lake City, which described how certain rivet holes in the pipe were made by shots from the engineer's

rifle. The writer asked the company's engineer, Mr. R. M. Jones, as to the truth of the story, and, contrary to expectation, the reply was, in the main, a confirmation of the report, although the holes were not for riveting, but for cutting out: Mr. Tratman.

"The story which circulated originally was about right. Have no idea who started it, but believe it was in one of the Pittsburg papers. The facts are, we had a standpipe of ½-in. steel, 7 ft. in diameter, which required three holes for connecting the pipe lines from different directions; each of these was 54 ins. in diameter, and the plate had to be cut out; therefore we shot it out instead of chipping it out. The apparatus used was merely one of the modern Winchester guns, using smokeless powder, or dynamite, with long leaden bullets, copper cast. These are the facts, and you are at liberty to use them as you desire."

GEORGE H. PEGRAM, M. Am. Soc. C. E.—A perusal of this excellent paper by one who has been familiar with the work therein described during its construction leaves the impression that sufficient credit has not been given to the chief engineer—no doubt unintentionally. Mr. Pegram.

The natural advantages for the installation of the plant are remarkable. A large impounding reservoir obtainable by a comparatively small dam, a large head of water obtainable in a comparatively short distance, return of the waste water to a natural river channel, by which it is conveyed to a large tract of land for irrigation, form the basis for an ideal plant.

The engineering difficulties, however, were greater, probably, than have been overcome in any other similar work. The wooden pipe line for nearly its entire length is supported upon the precipitous side of a narrow cañon of the most distorted and rugged hard-rock formation in which excavation had to be made at the constant risk of obstructing the river or endangering the much-traveled road in the bottom of the cañon.

The steel pipe line the writer understands to be the largest in the world. If the best results, or even good results, have been obtained under such conditions, it is believed to be due to Mr. Bannister's thorough study and constant effort to reach a better conclusion, even when it would seem that a sufficient result had been obtained. Mr. Bannister, recognizing the value of the location, had for years worked to secure the construction of such a plant. At the time the author of the paper was retained, the pipe line, with the exception of connections, etc., had been designed and a part of it built.

The steel pipe is unique in preserving a practically constant diameter, with no obstruction to the flow of water except the rivet heads, which are conically formed in order to present the least resistance. The large resistance heretofore observed in riveted pipes undoubtedly comes, largely, from lap joints, whether the pipe is constructed with alternating large and small rings, or with rings fitted inside at one end and outside at the other, similar to stove-pipe joints. It would be a valuable contribution to the existing data on the resistance to the

Mr. Pegram. flow of water in riveted pipes if experiments were made on the Ogden pipe.

With reference to remarks which have been made upon the riveter which the writer designed to do the work in the trench, it can only be said that the object was to drive the rivets with pressure that might be held on to them until they had partially cooled. It is very evident that one cannot hold on to $1\frac{1}{8}$-in. rivets and drive very many in a day. As an evidence of the excellence of the work done with this machine, all of the rivets in the round-seam field connections, and some of those in the longitudinal seams of the portion of the pipe tested, had been driven by this machine, and none of the rivets were cut out for replacement previous to the test, nor in any way tightened, so the result was deemed highly satisfactory. The machine was designed to drive two rivets at a time, although it was equally capable of driving one rivet. Although this machine was entirely unique, no changes in its construction and no repairs were required during its work of several months; and while the machine, in the light of its past use, can be improved, its discontinuance by the contractor was dictated by commercial reasons based upon the payment to be made for its use.

With respect to the proposed dam, aside from economy and its more scientific method of the distribution of stress and the facility for repair, it is believed that the type would offer great advantages in places like this, where there is a large underground flow of water and very little room for diversion channels, as it provides a method by which isolated piers may be built, allowing the water to flow between them until near the completion of the work. When concrete is used better work can be done in isolated masses, which can be built continuously, thus securing more perfect bond.

Mr. Henny. D. C. Henny, M. Am. Soc. C. E.—With a maximum flow through the pipe line of 250 second-feet the effective head on the wheels will be about 440 ft. with the reservoir full, and 381 ft. with the reservoir drawn down, corresponding to 12 500 and 10 800 gross H.-P., respectively. It will be seen that a fluctuation of 1 700 H.-P. exists. To make this available, machinery to develop the maximum amount must be provided. The entire pipe line had to be built to resist an extra pressure of 59 ft., and certain other expenses were incurred, such as the use of 72-in. pressure gates, stand-pipe, overflow shaft, air valves, etc., for which more economical structures could have been substituted. As this extra power cannot be depended upon at all times, it is not clear to the writer that its value is proportionate to its cost. Assuming that it is, the writer wishes to ask for what reason there was no economy in adopting a higher stage of low water in the reservoir and locating the pipe line correspondingly higher, thereby decreasing maximum pressures and cost at the expense of a small wedge of water in the bottom of the reservoir left unavailable.

The short tunnel, No. 7, appears from the plan to be situated close to the sloping wall of the cañon. The rock must have seemed remarkably sound and free from seams to justify the omission of lining. Moreover, in the absence of long tapering connections between the 6-ft. round pipe and the 9-ft. square tunnel, considerable loss of head must result at times of maximum flow. Mr. Henny.

The author in describing the wooden-stave pipe states that he believes its diameter to be greater than that of any conduit of the kind previously built. The writer understands that there are many short pieces of large pipe in New England used for conducting water to turbine wheels. A stave-pipe conduit 6 ft. in diameter was built by J. T. Fanning, M. Am. Soc. C. E., at Manchester, N. H.* Two other pipes of the same diameter were built by Mr. C. P. Allen, of Denver, one on the Maxwell Grant, in New Mexico, and the other at Gothenburg, Neb. Another pipe 6 ft. in diameter was built by the writer, in 1893, near Poso, Cal. The use of Douglas fir in stave-pipe construction can hardly be called a new departure, as almost all the stave pipes built in Washington, Oregon and British Columbia were constructed of that material.†

As regards the details of the stave pipe, the writer believes that for 6-ft. pipe a net thickness of stave of 2 ins. is rather light to insure rigidity, especially considering that in case of accident or sudden change of flow the air valves cannot operate until after the formation of a partial vacuum. A 12-in. minimum break of joint of the staves is very short, as 3 or 4 ft. can ordinarily be obtained without extra cost, thereby increasing the longitudinal strength of the pipe. If this short break was found to be necessary to produce the required curves, the writer would have preferred to use narrower staves.

Dependence was placed on the swelling of the staves to tighten the seam joints. This implies leakage at first filling, which it is believed can and should be avoided by the proper cinching of the bands.

In limiting the calculated unit strain to 14 660 lbs. on steel with 55 000 to 65 000 lbs. tensile strength, the possible factor of safety in the body of the hoop is somewhat less than four. This is further reduced, as no account has been taken of the strain caused by the pressure of stave upon stave that must exist if the pipe is tight, whether produced by swelling or by cinching, and which is additional to that resulting from the water pressure. While it is not proportionately large in this case on account of the comparatively small thickness of the staves, and is, moreover, hard to determine, the writer sees no reason for neglecting it. The factor of safety of the entire hoop is believed to be more seriously reduced by the character of the connecting shoes. It would seem that if the complete hoop were placed

* See *Transactions*, Vol. vi, p. 69.

† See *Transactions*, Vol. xxxvi, p. 15.

Mr. Henny. around an unyielding circle and tested to destruction, distortion of the loop and of the shoe would follow. The bearing of the loop against the thin steel walls of the shoe also appears insufficient.

On the pipe itself the bands cannot be tested in this manner, as the lumber would buckle long before the breaking point is reached. Nevertheless, this connection should be as strong as the body of the bolt, or metal in the bolt is wasted and the assumed factor of safety seriously reduced. Possibly this matter has been satisfactorily settled by actual test, in which case the author would add to the value of the paper by stating the results.

Mr. Adams. ARTHUR L. ADAMS, M. Am. Soc. C. E.—The works of the Pioneer Electric Power Company are of more than usual interest among the many plants of similar type which have been constructed throughout the West during recent years. It has been often exceeded in the height of effective head, is not novel in the use, diameter or construction materials of the stave pipe employed, and though fully abreast of present practice in length of transmission and height of voltage employed, is soon to be greatly out-distanced in both of these particulars if work at present under contract elsewhere is carried to successful completion. By reason of its magnitude, however, the work easily takes front rank among the high-pressure water-power development and long-distance electrical transmission plants in this country. It is also worthy of especial note because of the conspicuous care with which the general scheme, as well as the important details, have been worked out; and, though one may differ as to the propriety of some of the minor details as presented, the striking evidence of thoughtful and intelligent care in the treatment of the entire scheme certainly commands admiration.

The writer sincerely hopes that this description of a practically completed work of such interest will hereafter be supplemented by a complete statement of the action of the various parts under the test of actual service. A comparison between what was anticipated and that actually realized would doubtless prove very profitable and interesting.

The author is mistaken in thinking the stave pipe a pioneer, either in its diameter or in the use of Douglas fir for staves. Several conduits 6 ft. in diameter have previously been built, while the same quality of timber has been repeatedly employed in the states of the Northwest, and in at least one instance in Wyoming.

The care which has been taken in avoiding all extreme fluctuations of pressure in the stave pipe, arising from the almost unavoidable interruptions to the continuity of flow, will prove very advantageous, as will also the shortening to the least possible length of the closed steel conduit leading from the last relief overflow directly to the power station.

Referring to the details of the stave-pipe design and construction, as suggested by the author, the shoe is certainly light, and if tested to destruction in connection with its accompanying band would certainly show evidence of crippling long before the ultimate strength of the band would be reached, though complete failure would probably not result, because of the support given the sides by the external loop and internal threaded end of the encircling band. An excess of strength should always be given the shoe because of the section being in much less favorable form for resisting corrosion than is the circular band section. These shoes would doubtless give no trouble during erection, as is stated by the author, since very little tension can be put upon ⅝-in. and ¾-in. bolts of the length used, when the leverage of the wrenches employed is limited to 10 ins. This limit answers very well for pipe and bands of much smaller diameter, but in the present case would preclude all possibility of the bands being drawn to anything like the tension subsequently developed by the water pressure and the swelling of the staves, which tension is the least that can be applied during construction in order to insure a tight pipe when first filled, unless the filling be done exceedingly slowly and thus coincidently with the swelling of the wood. The staves are somewhat thinner in their finished shape than has usually been customary in building pipes of this diameter, but the writer sees no especial objection to this if sufficient care be exercised in properly tamping the back-filling and avoiding too great a depth of cover. Mr. Adams.

It is pleasing to note that the claims of wooden stave pipe for wonderful economy in first cost when built for moderate pressures, unusual ease of transportation and erection, even in very inaccessible places, and general adaptability for meeting the demands for a first-class conduit at a minimum of cost for the conveying of water under moderate pressures, have been recognized by the engineers charged with this work and have been fully vindicated in the result. It cannot be otherwise than that the merits of this class of pipe, when intelligently designed and carefully built, must ultimately lead to its greatly extended use throughout the whole of this and other countries.

The adopted plan for a masonry dam is a marked departure from all previous practice. The increased necessity for securing excellent construction work and the apparent dependence of the entire structure upon the integrity of each arch seem to the writer, however, to be objections sufficiently weighty to render so radical a departure from all precedent of doubtful expediency.

Henry Goldmark, M. Am. Soc. C. E.—In closing the discussion, the author wishes to thank those members who have supplemented the information given therein by additional valuable data, and have pointed out certain errors of statement. The purpose in writing the paper was to give a somewhat detailed account of a very interesting Mr. Goldmark.

Mr. Goldmark. work with which it was his privilege to be connected during the period of active construction. Written at a distance from the works described, it is unavoidably lacking in completeness, and the author is conscious of its shortcomings in other respects. He wishes, however, to disclaim emphatically any intention of giving insufficient credit to the chief engineer of the company, whose full responsibility for the design and execution of the work is repeatedly referred to in the text of the paper. He greatly regrets that his meaning should have been misunderstood. It is proper to add, that the paper was prepared at the request of Mr. Bannister, who, after its completion, kindly revised and approved it before it was printed.

The question of the necessary regulation of the machinery under sudden changes in loading was duly considered in its design. It is believed, as stated by Mr. Hayward in his discussion, that the electric governors adopted, together with the heavy fly-wheels, will be ample to produce speeds sufficiently uniform for all practical purposes.

The use of turned bolts instead of rivets was adopted for the bridges on the pipe line mainly to avoid the necessity of bringing skilled riveters from a distance. The shopwork being excellent, the use of bolts proved quite satisfactory.

In answer to the criticism of the details of the shoes and bands of the stave pipe the author personally prefers a somewhat heavier construction, though some tests of the straight bands indicated that the strength of the connections is greater than that of the plain rods.

The thickness of the staves (2 ins.) is apparently somewhat scanty, but the completed pipe has on several occasions been subjected to severe strains from landslides, etc., and has shown even greater strength than had been expected. A thin stave has the great advantage of thoroughly absorbing water, and thus resisting decay.

The 12-in. break of joint in adjacent staves is the minimum permitted by the specifications, but the average break is considerably longer, and a break of $3\frac{1}{2}$ or 4 ft. is not uncommon. It may be added that the leakage, at the first filling of the pipe, was slight.

As to the desirability of adopting a higher stage of low water in the reservoir and locating the pipe line correspondingly higher, it may be said that the low water-line actually adopted permits the use of the pipe line at all stages of the river and previous to the construction of the large dam, which has not yet been built. A higher location of the conduit would cheapen the wood pipe slightly, but would have no appreciable influence on the cost of the steel pipe, while the change would probably increase the expense of excavation considerably.

The connections of the 6-ft. pipe in Tunnel No. 7 are long tapering connections of concrete, so that any considerable loss of head is avoided. The rock in this tunnel appeared sufficiently sound to permit its use as a conduit without a lining.